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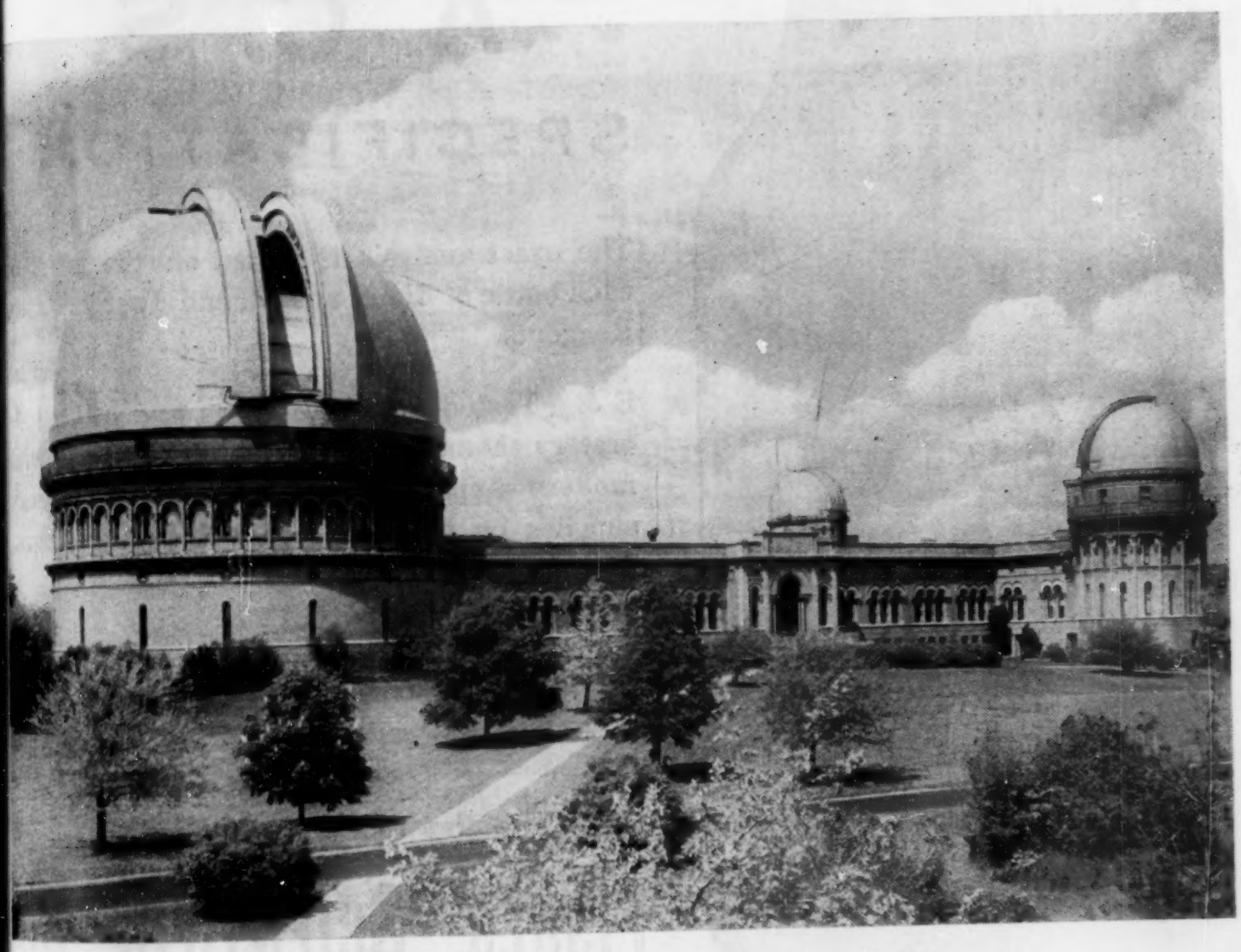

The Yerkes Observatory of the University of Chicago

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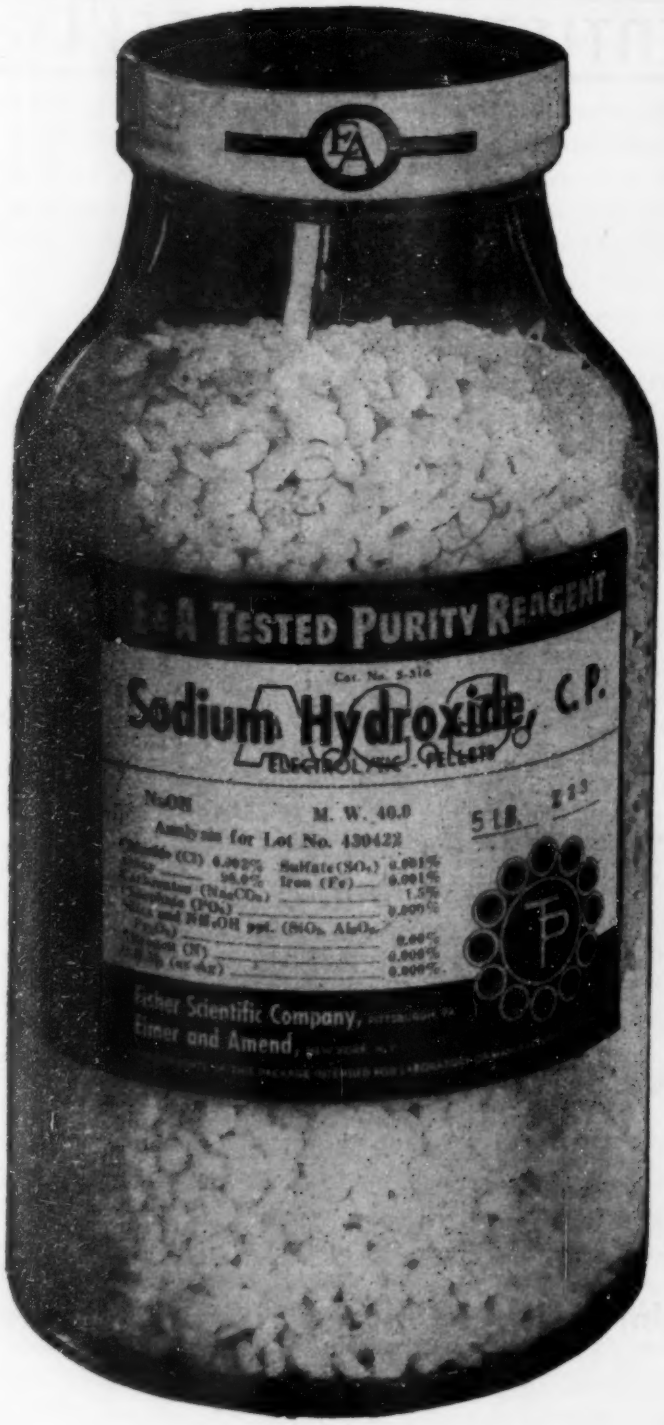

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The Department of Astronomy of the University of Chicago

Robert M. Hutchins, *Chancellor*

MY ASSOCIATION WITH ASTRONOMY is an association with Otto Struve. I have never studied the subject and never attempted to understand it. I believed in Mr. Struve. I believed in his judgment of men, in his standards of scholarship, and in his aims for his Department. I was sure that he knew the difference between a first-rate man and a second-rate man and that he would not tell me a man was first-rate if he were second-rate. I was sure that he knew the difference between a big department and a great department and that he wanted a great one. He did not want a great department so that he could brag about it; he wanted it so that the members of the Department and the University could make the greatest possible contribution to the advancement of knowledge. I knew that when Mr. Struve made a financial recommendation, he was being as economical with the University's funds as I would be, and often more so.

All I ever did for Mr. Struve was to encourage him. He had the ideas and the plans. He had the intelligence and character that commanded my respect, even when I didn't know what he was talking about. The difficulties he encountered were many. It was necessary for him not only to reconstruct a department in the midst of the Great Depression but also to operate it at a distance from the University. For long periods he had to give up his research to see to the most harassing kind of housekeeping problems in Wisconsin and Texas. All I did was to tell him the truth—that he was doing a great job.

Under Mr. Struve's leadership the Department of Astronomy set new standards of research as well as new standards for the quality of the staff in the Division of the Physical Sciences at the University of Chicago. The record of the Department has been an inspiration to the whole University.

When the Depression arrived, we could all see that research was going to be hard hit and that research in fields not immediately practical was going to suffer more than any other kind. Research in fields which required vast expenditures for new capital equipment was going to be almost impossible unless universities could pool their resources. Mr. Struve was not alone in his interest in cooperation among universities. I was also interested in cooperation in astronomy because (1) I foresaw that we would lose him unless we could find him a place to look at the stars where he would have some chance of seeing them, and (2) I could not imagine where we would get the money to build an observatory under clearer skies.

By the time the McDonald bequest to the University of Texas was finally settled, Mr. Struve had built up a good Department of Astronomy. The University of Texas had none at all. At the suggestion of Mr. Struve and Dean Henry Gordon Gale I telephoned President Benedict at Austin and obtained his immediate consent to consider a proposal involving the combination of Texas' Observatory and Chicago's Department. Mr. Struve did the rest. The peaceful and prosperous relationship which Texas and Chicago have enjoyed for many years is a testimony to the possibilities of university cooperation—at least when Mr. Struve is the connecting link.

Mr. Struve has brought other universities into his orbit by making observing time available to them in Texas, and the end is not yet. The possibilities of cooperation with institutions which are without the funds required for a modern observatory are far from exhausted.

Under the leadership of Otto Struve the Department of Astronomy of the University of Chicago has made important contributions to the art and science of astronomy. It has given new impetus to research in its field; it has proposed standards for the emulation of scientific workers in every field; and it has demonstrated that universities can work together. This is indeed a great record.

To celebrate the 50th anniversary of the founding of the Yerkes Observatory and the American Astronomical Society, a special session of the Society is being held at Williams Bay, Wisconsin, site of the Observatory, on September 6. On this occasion the editorial office of *Science* takes pleasure in presenting a series of articles by those who have been intimately associated with the achievements of this great Observatory.

Some Reminiscences of the Yerkes Observatory, 1898–1904

Walter S. Adams

Director Emeritus, Mount Wilson Observatory

THE PERIOD OF 50 YEARS WHICH HAS elapsed since the dedication of the Yerkes Observatory has been one of transformation in much of the field of astronomy. It opened at a time when visual observations with telescopes were still a major factor in observatory activities, photographic methods were in their infancy, the spectrum was studied empirically, and cosmogony was almost a completely sealed book. The period ends with visual observations greatly reduced in amount, although still holding an important place, with photographic methods applied almost universally and enormously improved and extended, with the spectrum analyzed and used as an extraordinarily powerful tool to seek out physical processes in the sun and stars, and with a clear and logical picture of a physical universe beyond the imagination of the astronomer of 50 years ago.

The Yerkes Observatory has taken a notable part in these great developments. It was fortunate in having as its founder and first director a man of remarkable insight and initiative, with a clear understanding of the major problems of astronomy and an almost intuitive perception of the fields of investigation which would yield the greatest returns. Although primarily a solar physicist, George Hale always emphasized the place of the sun among the stars and the necessity for applying to the stars the knowledge derived from their nearest representative. So, we find during his years of directorship not only marked advances in the methods and instruments used for the study of the sun, but also developments in stellar research which have proved remarkably fruitful in later years. He was one of the first to recognize the possibilities of the reflecting telescope, then a much neglected instrument in the United States, for both direct photography and spectroscopy, and secured from his father the gift to the Observatory of the 60-inch mirror which was later used in the first large reflecting telescope on Mount Wilson. Hale also made a great advance in the application of powerful spectrographs to the photography of both solar and stellar spectra. Realizing that spectrographs attached to moving telescopes must necessarily be limited in size and length, he developed the coelostat and concave mirror into a standard type of telescope for solar observations, and planned the use of the coudé focus of large reflecting telescopes for corresponding investigations of stellar spectra.

In other fields Hale's contribution was equally important. He appreciated at once the advantages of photography with a long-focus telescope for measurements of stellar parallaxes and brought Schlesinger to the Observatory to use the methods he had developed in this fundamental but difficult branch of positional astronomy. He encouraged Ritchey to undertake photography through yellow color filters at the 40-inch telescope, a project which resulted in some of the finest photographs of the moon, star clusters, and brighter nebulae ever obtained. The 24-inch reflecting telescope was also built at this time, and in Ritchey's hands began, in friendly rivalry with the Crossley reflector of the Lick Observatory, to penetrate into the domain of the more distant nebulae. The fundamental work in stellar radial velocities, under the immediate direction of Edwin Frost, was supported strongly by Hale, and benefited greatly from his advice and optical and instrumental skill and knowledge. He also established a department of stellar photometry, in which Parkhurst carried on a long series of measurements of magnitudes of variable stars, and invited E. F. Nichols to attempt the radiometric investigation which resulted in the first successful measurement of the heat radiated by a star. Finally, Hale, who was a physicist at heart, carried out in the laboratory, either by himself or with collaborators, several spectroscopic investigations designed to imitate or help to explain phenomena observed in the sun and stars. The maintenance of such an intimate relationship between telescope and laboratory instruments operated under controlled conditions was a cardinal principle in Hale's scientific career.

It is clear from this brief summary that Hale had solved in a most efficient way the difficult problem of utilizing a large, existing telescope to the best advantage. In later years he was able to reverse the situation to a considerable extent, building instruments to fit the problems in mind, and his experience at the Yerkes Observatory then proved of the utmost value. We can readily understand, then, why Hale's colleague, Frost, could have given to the 40-inch refractor the title of "the busiest great telescope in the world." Used for solar observations during the day and for a wide variety of stellar investigations by night, the 40-inch telescope could well have carried above the entrance to its dome the sign on the doors of numerous Chicago saloons of those unregenerate days: "We have thrown away our keys. Open all the time."

My relationship to the Yerkes Observatory began in 1898 when, on the advice of Frost, who had been my teacher in astronomy at Dartmouth College, I undertook

graduate study at the University of Chicago and spent some months at the Observatory in acquiring practical observing experience on the sun under Hale and in stellar spectroscopy under Frost. Soon afterward I went to Germany for study at the University of Munich, but after about a year the offer by Hale of a position as assistant at the Observatory led to my return in the early summer of 1901. I remained until May 1904, when Hale organized the first expedition to Mount Wilson.

The Yerkes Observatory was dedicated in October 1897, so that, when I first knew it as a student the following year, recollections of the occasion were fresh in the minds of everyone. These have been supplemented by an interesting book of records and clippings collected by Frederick Seares, who was present as a delegate from the University of California. This book, through his kindness, is now in the library of the Mount Wilson Observatory.

The dedicatory exercises occupied five days, the first three of which were devoted to meetings, addresses, and demonstrations of instruments and apparatus, primarily for the benefit of the visiting astronomers and other scientists. On the fourth day special trains left Chicago for Williams Bay, bearing Mr. Yerkes, President Harper, and the Trustees of the University, together with many city officials and other prominent citizens. The formal presentation of the Observatory and its acceptance were made on this day. The trains returned to Chicago late in the afternoon in time for an evening dinner tendered the visiting scientists by Mr. Yerkes, at which President Harper served as toastmaster. On the fifth and last day the buildings and laboratories of the University were inspected, the exercises closing with a reception to Mr. and Mrs. Yerkes and the delegates in attendance.

No one can look back upon this dedication without realizing how strong and genuine was the interest of the citizens of Chicago in this great gift to science. Some 800 persons attended the final exercises at Williams Bay, and all the Chicago newspapers carried long and detailed accounts of the day-by-day proceedings. They had good reason to feel that the new observatory was peculiarly their own. It was given by a Chicago man to a Chicago institution, and the man who was responsible for its establishment and was its first director was born and lived in Chicago. Naturally, the newspapers were not inclined to conceal these facts, nor did they fail to issue headlines which sound remarkably familiar even now. "Great Eye to Open," "Great Lens Focused," and "Feast of Wise Men" were some of the expressions which may well serve again at the dedication of the 200-inch telescope. Although the principal feature of the 40-inch telescope was correctly named on this occasion, astronomers know, to their sorrow, that it takes more than half a century to convince the average reporter of the difference between a lens and a mirror.

The chief interest in such an event consists in the men who were present, and numbered among them were nearly all those whose names were so familiar in astronomy at the beginning of the century: Hale, the man of 29, who had seen the first of his great dreams come true; Simon Newcomb, the rather grim dean of American astronomers; Keeler, whose brilliant career was so soon to close; Pickering of Harvard, with his diversified astronomical interests; two of America's distinguished physicists, Michelson and Henry Crew; Runge, the German spectroscopist; and the group of famous visual observers which included Barnard, Burnham, Comstock, Doolittle, and Ormond Stone. With such a variety from which to choose, the reporter, with his eternal desire for "human interest," had a field day, for the element of picturesqueness was by no means lacking. In particular he preyed upon Burnham, the great double-star observer, to whom Newcomb, in the course of his lecture, had paid a special tribute for his remarkable discoveries with small telescopes. Under the headline, "Burnham Is in Focus," the reporter pictured the unconventional Burnham on the stage at Newcomb's lecture as "a little man who wore neither gown nor cap, but dropped into his place, slid down to about the middle of his back, and folded his arms. . . . His face was thin and his hair seemed bent on going where the wind listeth (*sic*)." At Newcomb's reference to him the reporter said that "the little man seemed to slide down another inch in his chair and pull his arms into a tighter fold." As I came to know Burnham shortly afterward, the description seemed to me a fairly accurate one, with the possible exception of the last statement. At that stage in the lecture there is a strong probability that Burnham was asleep.

It was an interesting and highly individualistic staff that was gathered together at the Observatory in these early years. The vivid personality of Hale, with his eagerness and enthusiasm and a mind constantly searching for new methods and devices, was balanced by the more deliberate Frost, whose conservative judgment was the heritage from a long line of New England ancestors. Together they formed a most efficient combination, with Hale usually the originator of a plan and Frost the counselor and critic. This difference in outlook almost invariably assured a well-considered decision which had been judged from many points of view.

Barnard and Burnham were great figures in the field of visual astronomy, to which the science has been indebted for many of its most spectacular discoveries. Each was a master of that difficult instrument, the filar micrometer, but their temperaments were very different. Although a most active observer, Burnham was philosophical in his outlook: if a night was stormy or the seeing was impossibly bad, Burnham took the matter calmly; there was always a good book to read, or someone to talk to, or even a game of whist to play if sufficient players were available. Barnard, on the other hand, felt a sense of injury and would be in the depths of despair

if the night was bad, or, conversely, would be on the top of the world after a clear night with good seeing. Barnard's absorption in his work was almost incredible. On a stormy night he would often go out into the rain every few minutes to observe the direction of the wind and the amount of rainfall in the hope of being able to predict a clearing. On clear nights he would be in the dome long before dark, observing some bright star or planet or glancing impatiently into the field of the telescope until his object became visible. He had many of the simple and lovable characteristics of a child, and it was a deep pleasure to me in later years to renew at Mount Wilson the warm friendship begun at the Yerkes Observatory.

The two other members of the staff with whom I was chiefly associated at this time were Ellerman and Ritchey. Ellerman had been an assistant to Hale for several years at the Kenwood Observatory and was a remarkably skillful and resourceful observer. His long experience with instruments made him invaluable in the adjustment and testing of the experimental apparatus which preceded the construction of more permanent equipment such as the Rumford spectroheliograph. He was an excellent photographer, highly competent with machine tools, and always ready to help visiting scientists who came to the Observatory for special investigations, or inexperienced students or assistants like myself, who were trying to gain some knowledge of observational astronomy. Ellerman had many outside interests such as music, tennis, golf, and swimming, and his attempts to stalk a wild goose with a rifle over the ice in the middle of Lake Geneva were a regular feature of the winter season.

Ritchey was a perfectionist in his methods of work and had a tendency to surround his optical figuring and his observing with a somewhat unnecessary atmosphere of secrecy and even awe. Nevertheless, his results were in general proportional to the care which he took. Several of his superb mirrors, together with the photographs which he made with the Yerkes Observatory instruments and in later years at Mount Wilson, bear witness to his skill and form a contribution of great and permanent value.

Without entering upon any detailed description of the work of the Observatory during these early years it may be of interest to comment briefly upon some of the more important investigations then in progress. Hale's primary interest was naturally in the spectroheliograph, which he had invented only a few years previously. His chief object was to explore the possibilities of this instrument in solar research, and with this in view he designed, after considerable experimentation, the Rumford spectroheliograph. As used on the 40-inch telescope, it proved remarkably efficient, enabling him not only to study the distribution of gases of various elements in the solar atmosphere through the use of their corresponding spectral lines, but also, in the case of calcium, to explore the distribution in depth by using different portions of the same line. The need of greater dispersion to exploit fully exacting observations of this kind led Hale to plan the coelostat type of fixed telescope with which spectroscopic instruments of any desired focal length could be used. There can be little doubt that the excellent photographs made with the Rumford spectroheliograph showed some traces of the vortical structure around sunspots, the full recognition of which at Mount Wilson led Hale to his remarkable discovery of the magnetic field of spots.

Solar spectroscopy, although necessarily limited by the length of the spectroscopes which could be attached to the large refractor, was also carried on successfully. The fine solar seeing often found at the Observatory, especially during the autumn months, led to the detection of the green carbon fluting in emission at the edge of the sun, and many other bright chromospheric lines were observed and listed. The lack of sufficiently powerful spectrographs, and the absence during these years of large sunspots because of the phase of the spot cycle, were responsible for the limit on the number of observations in this rich field of study.

In stellar spectroscopy chief emphasis was laid upon measurements of radial velocity, although the important investigation of Secchi's fourth type stars by Hale, Ellerman, and Parkhurst dealt largely with the physical aspects of their spectra. Considerable attention was devoted to the spectrum of Nova Persei, the brilliant nova of February 1901. It is interesting to realize that the large telescopes of the world are still obtaining important data on this nova nearly 50 years after its outburst. Frost wisely selected for intensive observation of radial velocity the relatively neglected class of B-type, or helium, stars. The lines in the spectra of these stars are usually diffuse, and several photographs were needed to provide a reasonably accurate value of the velocity. As a result, the number of stars observed increased but slowly. A discussion of the radial velocities of 20 such stars, published by Frost and Adams in 1903, showed clearly, however, that the average motion of these stars is exceptionally small, a conclusion which has proved important in later discussions of stellar motions. Numerous spectroscopic binaries were discovered in the course of these observations.

The micrometric observations of Barnard during these years ranged over a wide field, from measurements of the diameters of the major and some of the minor planets to the enormous labor involved in the triangulation of many stars in globular star clusters. The extraordinary accuracy of these visual measurements has always been a source of wonder to astronomers, and he was well named "Barnard of the wonderful eyes." His determinations, for example, of the parallax of 61 Cygni and of the positions of Eros compare favorably with the best photographic results. My most interesting experience with Barnard's observing occurred on one fine summer night when I looked in at the dome of the 40-inch telescope and found him measuring the position of the fifth satellite of Jupiter, which he had discovered at the Lick Observatory some years

earlier. This is a difficult object because of the glare of the great planet, and many astronomers have never even seen it, but Barnard was measuring it steadily as it moved outward toward elongation and then turned back again. Time was valuable, and I volunteered to record his measures so that he would not have to remove his eye from the eyepiece more often than necessary. The figures slowly increased, became stationary, and then began to decrease. The following day Barnard showed me a curve on which the measured values fell almost as closely as if they had formed a part of the curve itself. The fact that Barnard, at the height of his observing powers, time and again observed the planet Mars under the best of conditions with telescopes of various apertures, and could never detect the very fine markings described by Lowell and a few others, would seem to provide the most conclusive evidence bearing on this vexed question.

Burnham was also an extraordinarily able visual observer but did not have Barnard's catholic interest in almost every object in the sky. He lived exclusively for double stars, and there is a tradition that one day he mentioned casually to Barnard having seen a comet in the field of one of his double stars on the preceding night, but he had not measured its position. The comet was a new one, and Barnard's horror can well be imagined. Burnham was an inveterate cigar smoker, and on the morning following a night's work a fairly accurate analysis of his observing schedule could be made from the intricate trail of tobacco ashes on the floor of the dome. On one occasion his smoking habits resulted in a fire in his office which partially burned the couch on which he was taking a nap. Burnham was a delightful companion, and on stormy nights two or three of our younger group would often gather in his office to listen to his stories or to play a game of whist, of which he was very fond. Mrs. Frost occasionally visited us to form a fourth player at the table.

Burnham's observing nights were always at week ends, since he served as a district court reporter in Chicago during the other days of the week. An unfailing sign of his coming, for which we used to watch eagerly, was the arrival at the Observatory of a case of Burgundy. Whether his taste for wine was acquired during his years in California, whether it was due to the fact that the water of Chicago at that time often had to be boiled, or whether it formed part of his general Bohemian instincts we never knew.

The pioneering work of Schlesinger in developing methods and placing on a firm foundation photographic determinations of stellar parallax, visual photometric observations of variable stars by Parkhurst, and various laboratory investigations, mainly spectroscopic in character, completed most of an active and productive program during these years. The radiometric measurements by Nichols of the heat radiation from Arcturus, Vega, and two of the planets, made in the summer of 1900, attracted much attention from scientists. It is interesting to note that these first results obtained in a difficult field show the marked difference in the amount of heat radiated by Arcturus and by Vega, two stars of nearly the same apparent magnitude. An amusing incident occurred during these observations. Charles St. John, then, I believe, on his first visit to the Observatory, was assisting Nichols in the adjustment and calibration of the radiometer, using for the purpose a candle flame in a field west of the instrument and about a quarter of a mile distant. Suddenly the vane of the radiometer rotated violently, and the spot of light used for measurement leaped completely off the recording scale. St. John had brought his beaming face into the path of light and had obtained a physical measure of his unfailing good nature.

The younger group at the Observatory during the last years of my stay included Philip Fox; Herbert Reese, later professor of physics at the University of Missouri; and Street, who assisted Ritchey in the optical shop. We were all of nearly the same age and lived at Mrs. Sawyer's house on the main road leading to Williams Bay. Miss Ware took her meals with us and had a most beneficial and civilizing influence upon a lively group, of which Fox was naturally the ringleader. R. James Wallace, known, of course, as "Hoot," and his family lived next door and was a close and always entertaining friend. Under such conditions and with the hospitality of the Frost, Barrett, Schlesinger, and Wallace houses available, we had the best of times together even in the comparative isolation of a small community in a Wisconsin winter.

As might be expected, the members of our group were usually engaged in trying to get the best of one another, and Fox was a master at the game. So Reese and I felt a grim satisfaction one Saturday evening in the fall of the year when Fox and Street, who had been absent all day, arrived at the house, limping, somewhat battered about the face, and extraordinarily uncommunicative. Some time before, we had been discussing the subject of football games between teams of rival high schools in southern Wisconsin, and Fox and Street, the athletes of our group, had announced that it would be most amusing and entertaining to join one of these teams and show its opponents how the game should be played. This was quite possible, since eligibility rules were unknown or remarkably elastic, to say the least. Reese and I had pretty much forgotten this conversation, but it seems that Fox and Street had selected this day and offered their services to a high school about 30 miles from Williams Bay. They were accepted without difficulty, but unfortunately the opposing team had gone them one better and negotiated with several husky mill hands in a neighboring steel factory. It took a long time to pry out of Fox the score of the game.

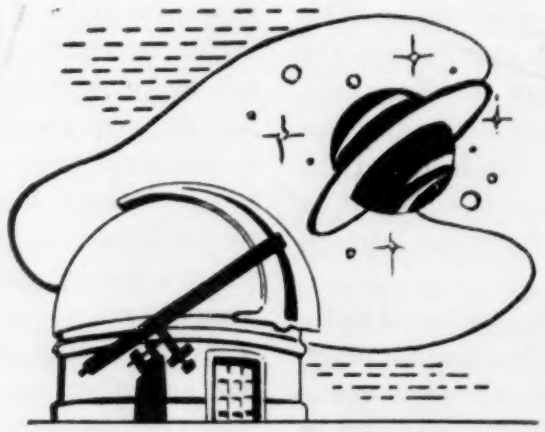
On another occasion Street was again a victim and Fox and I were the perpetrators, taking shameful advantage of Street's lack of knowledge of the constellations. One very cold winter night when Fox and I were at the Observatory a telegram arrived, announcing the discovery of

an 8th magnitude nova. We visited the dome, where we found Frost, I believe, considering the possibility of observing the star with the smallest spectrograph available. After some time we went home, awakened Street, and gave him the news, carefully omitting any reference to the star's brightness. Street was greatly excited and asked where it was, whereupon we pointed to the brilliant Procyon, riding high in the winter sky. "Gee," shouted Street, hurried on his clothes, and started for the Observatory along the path through the snow. Fox and I went to bed after safely locking our doors.

The lake and golf were naturally the chief centers of our outside interests at the Observatory. Once Fox and I made a trial swim on the day after the ice went out, but this experience was not repeated. Several of us tried to swim across the lake, but Fox was the only one to succeed, the coldness of the water discouraging those of lesser strength and endurance. The good ship *Argo*, a small sailing boat, was for some time the proud possession of Fox and Street, but not being expert sailors and having had to swim ashore a few times after capsizing in uncertain winds, they gradually lost interest in their venture and left to others the search for the Golden Fleece. The beauty of Lake Geneva in all its different aspects is one of my choicest memories of the years at the Observatory.

The golf course in its original form consisted of 6 holes laid out in the fields north and west of the great dome. There were no formal bunkers or traps, since the character of the course offered plenty of natural difficulties and hazards, consisting, as it did, of roughly mown hay fields with occasional bushes and thickets. The group with which I usually played included Hale, Frost, and Ellerman, and I remember our games together mainly because they brought out so clearly the individual characteristics of the players: Hale, with his eagerness and zest, making many fine strokes but occasionally "pressing" through overenthusiasm; Frost, deliberate and calm, stamping on the ground before a drive until he had settled his long frame into the most comfortable position; and Ellerman, who was normally our best player, studying his strokes with great care and usually executing them equally well. It was Ellerman who painted his golf balls red in order to play over the hard snow in winter, and who once amused himself by making a drive approximately half a mile long over the glare ice of Lake Geneva.

In assembling these scattered reminiscences of the early years of the Yerkes Observatory I have tried to give a picture, however slight and inadequate, of the individuals who made up the small group which started the Observatory upon its scientific career. The years were difficult ones financially, and auxiliary equipment was scanty and hard to obtain. Seen from the present point of view, a few of the problems investigated do not appear of the first importance; for physics, if not in the dark ages, was at least static, with the renaissance yet to come, and the means for interpreting the results of observation were still hidden from view. Nevertheless, the group of those years was an active one and had a leader of great vision and insight who prepared for what the future might bring; the able and highly trained staff of the present day, with greater instrumental resources and all the recent developments of modern science at its command, has shown brilliantly how great a structure may be erected upon the foundations laid half a century ago.



Studies of the Stellar System

G. P. Kuiper and W. W. Morgan

THROUGHOUT THE FIRST 50 YEARS OF the Yerkes Observatory investigations on galactic structure have been carried out on a substantial scale. Some of the principal efforts are described below.

The knowledge of our stellar system at the beginning of the century was only rudimentary. It was assumed from star counts to the 10th magnitude that the galaxy was a flat, disk-like system with the sun roughly at the center. But the overwhelming majority of the stars are fainter than the 10th magnitude. In fact, if all stars brighter than the 10th magnitude were eliminated, the Milky Way would not appreciably change its apparent shape and brightness; only the bright stars dotted on the luminous background would be missing.

One might suppose that, if star counts were made to the 18th instead of to the 10th magnitude, in fields properly distributed over the sky, the true picture of the galaxy would emerge. This approach was advocated by Kapteyn in 1904 in his Plan of Selected Areas, and the observations accumulated since then at several collaborating observatories have indeed led to a far more precise and complete outline of the galaxy. But progress in the interpretation of these star counts was seriously hampered by the lack of knowledge of so-called interstellar absorption. In fact, the first results based on counts to the 18th magnitude, made on the assumption that interstellar absorption was not important, have proved to be seriously wrong.

The Milky Way studies of Barnard and Ross at the Yerkes Observatory are complementary to the studies of the smoothed-out galaxy of the Selected Areas school. Barnard, in his beautiful *Atlas of selected regions of the Milky Way*, published by the Carnegie Institution of Washington in 1927, has shown the Milky Way to consist of a highly complex array of star clouds and dark markings. His efforts were a continuation of his earlier work at the Lick Observatory between the years 1892 and 1895 (Lick Publication 11, 1913) and owe their success to the gift by Miss Catherine Bruce, in 1897, which enabled Barnard to acquire a 10-inch "portrait lens," as he preferred to call it, figured by the great optician, Brashear. Ever since its completion in 1904, the Bruce telescope has aided the Yerkes astronomers in their galactic studies.

The tradition of high-quality Milky Way photography set by Barnard was continued by F. E. Ross. Ross had introduced into astronomy a new tool, the "Ross lens," an F/7 system with superb field qualities. With a 5-inch lens of 35-inch focus he obtained a set of extraordinarily fine negatives which have been reproduced in the Ross-Calvert *Atlas of the northern Milky Way*, published by the University of Chicago Press in 1934.

Both atlases are based on plates obtained by their authors largely at other observatories, notably Mount Wilson, and are fine examples of the value of interinstitutional cooperation.

Barnard's work with the Bruce telescope included one other program that has been a rich source of astronomical results. He covered a large part of the northern skies with first-epoch plates for subsequent proper-motion surveys with the aid of the blink microscope. The remarkable star, BD +4°3561, which carries Barnard's name, still holds the record in the amount of its proper motion (10".3 per year). Barnard's star, discovered in 1916, must have been a great stimulation for the completion of this program.

The proper-motion program was taken up by Ross after Barnard's death (1923). With great care he duplicated the Barnard fields and embarked upon the arduous task of examining the millions of faint stars on the plates for proper motion. The search was completed in about 8 years, during which well over 1,000 stars with large proper motion were announced. Among these Ross stars are some of the most interesting and faintest of the sun's neighbors in space. They have been a fruitful program for parallax determinations and statistical studies of the stellar population of the galaxy.

On a much smaller scale proper-motion searches have been carried out also on fields photographed with the 24-inch reflector. The first-epoch fields were taken for the study of variable stars, mostly by Parkhurst, and more recently for comets and asteroids, primarily by Van Biesbroeck. In 1916 Hubble repeated some of the former fields, as did Luyten and Ebbighausen more recently; while Van Biesbroeck quite recently duplicated many of his comet and asteroid fields. In all, an appreciable number of stars with large proper motion were found; the precision of the results was considerably higher than those obtained with the Bruce telescope.

The large collection of proper-motion plates in existence at the Yerkes Observatory has been the incentive for the compilation by Kuiper of a manuscript catalogue of all stars with proper motion larger than 0".3. Photographic observing charts were made by Kuiper and Miss Calvert for some 3,000 stars, all of which were observed for spectral type at the Yerkes and McDonald Observatories. Over 9,000 spectra were obtained which are used for the determination of spectral parallax and which, together with magnitude determinations, form an adequate foundation for the determination of the distribu-

tion of stars in the spectral type-magnitude or Hertzsprung-Russell diagram. If the distribution in this diagram is put on a numerical basis, it expresses better than any other diagram or table our information on the stellar population in space.

A final source of studies in proper motion, which has hardly been exploited so far, is found in the many excellent photographs of clusters taken with the 40-inch telescope. Both Ritchey and Barnard left many excellent negatives of globular and galactic clusters which are now invaluable because of the large scale of the 40-inch telescope and because of their age (many of them over 40 years). Some negatives have been recently duplicated and measured by Ebbighausen, but the greater part of this source of information is as yet untouched.

The importance of the proper-motion and subsequent parallax programs is not limited to the statistical data summarized in the Hertzsprung-Russell diagram. These programs are also basic for our information of stellar masses and absolute magnitudes (or luminosities). Together with data derived from eclipsing variables which can be observed spectroscopically, the parallax program, as applied to visual binaries, provides the basic data for the study of the mass-luminosity-radius relations. As such, they are fundamental for the present theories of stellar constitution and of energy generation. One important aspect of this work is the determination of mass ratios in visual binaries, which has been a subject of continuous study at the Yerkes Observatory for at least 30 years.

Mention should be made in this connection of a field of intensive activity throughout the Observatory's history —the observation and cataloguing of double stars. In the first two decades Barnard and Burnham contributed large numbers of observations to this field, and Burnham laid a foundation for all modern work on double stars by issuing his two-part *General catalogue of double stars within 121° of the North Pole* (Carnegie Institution of Washington, 1906). Later, this was supplemented by his *Measures of proper-motion stars* (Carnegie Institution, 1913). From 1916 to the present date, Van Biesbroeck has continued the tradition and has accumulated a great number of measures on many pairs of interest. Still more recently, Kuiper has paid special attention to pairs of importance for the mass-luminosity relation and has found a number of new objects in this class. The 40-inch telescope is equipped with an excellent micrometer, and the instrument as a whole is perhaps the best telescope of its kind for general double-star work.

Contributory to the study of the near-by stars have been important lists of radial velocities by Popper and Münch and of magnitudes by Seyfert.

Another kind of work now in progress with the 40-inch telescope is a program of spectroscopic absolute magnitudes and distances of the brighter stars, being carried on by Morgan and Bidelman. Among the most interesting types of stars for which information on the distances is being obtained are the luminous blue supergiants; these—even when apparently bright—are located at very great distances and thus allow us to obtain information concerning the absorption of light in space. Developments in methods in the course of the past few years now make it possible for us to determine the true brightness and distance of almost any kind of star now met with; the exceptional objects which cannot be dealt with directly form a vanishingly small percentage of the total number of stars which can be observed spectroscopically. Additional examples of these relatively rare, peculiar objects are being discovered in the course of the general spectroscopic program, and several remarkable and puzzling stars have been discovered recently by Bidelman. This research program therefore has a double result: the true luminosities and distances of the "normal" stars are being determined, and peculiar objects requiring investigation of an astrophysical nature are being discovered.

An entirely different field of galactic research, though connected with the pioneer work of Barnard, is that on the galactic nebulae. These studies have been important both for the distribution of nebulous material in the galaxy and for the scattering properties of such material. The research was carried out by Struve, Henyey, and Greenstein, after some remarkable early work by Hubble. In the course of this work Struve developed a novel instrument, the nebular spectrograph, which was first mounted on the 40-inch telescope and later transported to the McDonald Observatory. With it, extensive regions were found in the galaxy showing H_α in emission. Another notable contribution was the discovery by Elvey of the "galactic light," a dim reflection by interstellar material of stellar light falling on it. It was found as a residual brightness of the Milky Way after subtraction of all light attributable to stars.

A field of great promise lies in the application of the modern RCA photomultiplier tubes to astronomy. The Yerkes Observatory is participating in this development through the work of Hiltner, who has been observing eclipsing binaries of special interest.

Astrometry

G. Van Biesbroeck

THE CONTRIBUTIONS OF THE YERKES Observatory to astrometry were influenced during the first years by the two outstanding visual observers who joined the original staff. The first, S. W. Burnham, was at that time the recognized leader in the field of double stars. He discovered a great number of interesting pairs, the components being either very close or very unequal in brightness, and he used the 40-inch telescope to its full power to follow the orbital motion of the more difficult pairs. His monumental *General catalogue of double stars*, published by the Carnegie Institution in 1906, remained for many years an indispensable tool for all workers in that field. Since his retirement in 1915, the work on double stars has been continued by G. Van Biesbroeck, G. P. Kuiper, and, lately, D. Harris. This work has been the basis of most orbital computations done on visual binary stars in the last score of years. A large amount of micrometric work on double stars has also been done with the 82-inch McDonald reflector by Van Biesbroeck and Kuiper.

The second early observer, E. E. Barnard, had a much wider field of interest than Burnham. His enthusiasm as an observer established at the Yerkes Observatory the tradition of all-night work and of the utilization of every minute of available clear sky. He devoted the major part of his time at the telescope to the measurement of the relative position of stars in clusters in the hope of establishing internal motions in such systems. This was started at a time when it was not realized that photographic processes were infinitely superior to visual micrometric triangulation for that type of work and when no information was available concerning the great distances of clusters and the extremely slow motions to be expected in them. In Barnard's hands the micrometer was used more profitably in many other lines: he measured the diameters of planets, asteroids, and satellites; he followed the relative positions of Saturn's satellites and contributed many measures of the positions of comets as well as nebulae. He never failed to record the elongation of Jupiter's fifth satellite, the small body discovered by him in 1892 at the Lick Observatory.

The possibility of using the 40-inch telescope as a photographic instead of a visual instrument was not foreseen when it was first put in operation. At about the turn of the century Ritchey showed that by working in yellow light, for which the telescope was achromatized, excellent photographic images were given. For the best results this required the combination of isochromatic plates and a yellow filter as well as the double-slide guiding plateholder. The large scale given by the 62-foot focal length of the big lens procured a means of measuring positions with a precision never before attained, and at once the problem of stellar distances was inaugurated. On a grant from the then newly-established Carnegie Institution, F. Schlesinger spent the years 1903–1905 at Williams Bay, developing the method and investigating exactingly the precautions to be used in this most delicate operation. He obtained parallaxes for 27 stars, and the result was so successful that it marked the opening of a new era in astronomy. Up to that time only a handful of stellar distances had been obtained, none of which was too reliable. The gain in precision and speed with the new method made it possible to reach many stars and much greater distances. After Schlesinger left, the work was continued successively by Slocum and Mitchell, Lee, Joy, Van Biesbroeck, Mrs. Pettit, Moffit, Hetzler, Titus, and, after an interruption by the World War, Strand and Hall. Several other observatories joined in the campaign of measuring stellar distances after Schlesinger standardized the method of procedure. During the first third of this century several thousand stellar distances became thus available. Indirect methods calibrated by the photographic determinations allowed thousands of stars to be investigated for distance. Thereby the basis was laid for our knowledge of stellar luminosities and masses, for our modern concept of the size of the visible universe, and for far-reaching consequences in all branches of astrophysics. At present, stellar parallaxes are no longer determined wholesale with the 40-inch lens; the work is concentrated on a special group of stars, mostly faint, which have been shown by indirect methods to be at a measurable distance. The photographic process at the 40-inch refractor has been used in several other astrometric investigations: in the determination of mass ratios of binary stars (Van Biesbroeck, Huffer, Strand, Hall), in proper-motion work in the Kapteyn areas centered at +45° declination (Lee), and for the precise measurement of wide double stars by Hertzsprung's method (Strand).

The 24-inch reflector, which had been used mainly for photometric observations by Parkhurst and for studies on nebulae by Ritchey and Hubble up to 1922, has since proved increasingly useful for photographic astrometric work on faint objects: comets, asteroids, satellites, and proper-motion stars. With its aperture ratio of 1:4 it is a fast instrument photographically. It records in 5 minutes the faintest objects that can be seen in the 40-inch refractor. Many positions of asteroids fainter than are generally observed have been obtained with the 24-inch reflector by Van Biesbroeck, Struve, Chang, and, more

recently, Harris. By repeating the earlier exposures with this instrument, the changes in star positions after an interval of more than a quarter of a century can be found by the "blinking" process. Van Biesbroeck has detected many faint proper-motion stars in this way. The same observer has published long series of comet positions obtained photographically with the 24-inch reflector; in order to improve the orbits of these objects it is essential that they be followed over as long an arc as possible. Measures of comets have often been continued for months with the 24-inch reflector after most observers abandoned them because they were too faint. Such extended series are especially valuable in distinguishing between parabolic or slightly hyperbolic orbits and the elliptic ones which indicate periodicity.

The brightnesses of comets and their puzzling fluctuations also constitute studies from these photographic documents.

Stellar Spectroscopy

Otto Struve

ON THE WALL OF THE DIRECTOR'S office hangs an autographed portrait of Sir William Huggins. Once the personal property of G. E. Hale, it was presented by him to the Yerkes Observatory at the time of his departure for Mount Wilson in 1904. Huggins was probably the most famous of the early pioneers in astrophysics. In 1856 he had built a private observatory in the garden of his London residence at Tulse Hill, and had engaged in the study of the spectra of the stars by means of a small visual spectroscope attached to a moderately large refracting telescope. Three years later, Kirchhoff had succeeded in reversing two strong, dark absorption lines of the spectrum of the sun by placing a flame colored by sodium vapor in front of the slit, so that the lines appeared as two yellow emissions on top of the usual background of the continuous spectrum. The intensity of the background spectrum of the sun was reduced by a filter in this experiment. When Kirchhoff removed the filter, allowing full sunlight to fall upon the slit, the two lines were again seen as black absorption features "with an extraordinary degree of clearness." His announcement of the solution of the mystery of the Fraunhofer absorption lines followed shortly thereafter, and it was this announcement which inspired Huggins to write:

> Here at last presented itself the very order of work for which in an indefinite way I was looking. . . . A feeling as of inspiration seized me: I felt as if I had it now in my power to lift a veil that had never before been lifted; as if a key had been put into my hands which would unlock a door which had been regarded as forever closed to man [from Macpherson's *Makers of astronomy*, Oxford Univ. Press, 1933, p. 167].

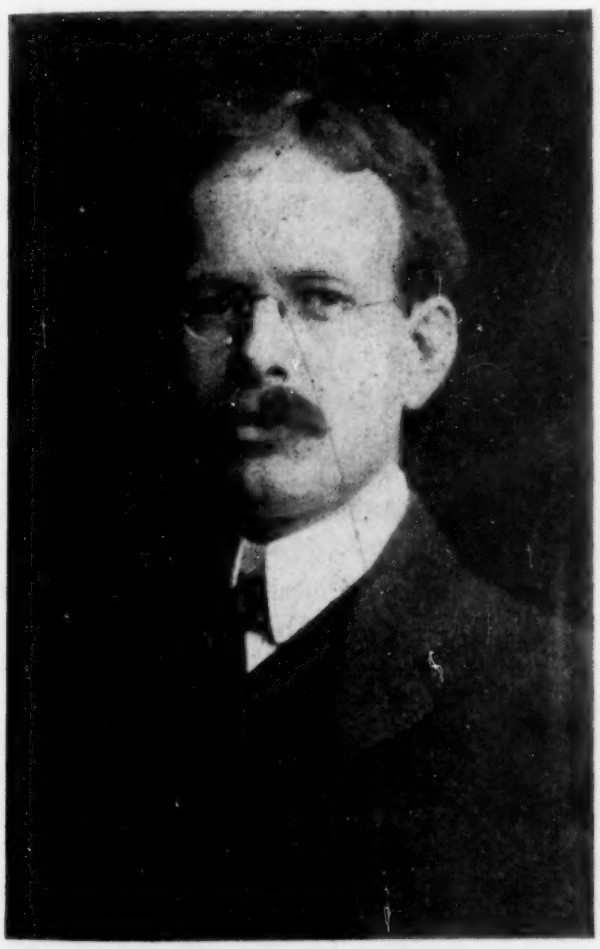
During the past 50 years three directors of the Yerkes Observatory have conducted their work under the watchful eyes of Sir William, and I believe that all three have often looked up to his portrait for guidance. My predecessors, Hale and Frost, had known Huggins personally, and his influence is easily discerned in their publications. My own work, though not so intimately connected with that of Huggins, unquestionably resembles his in character. Huggins was filled with the spirit of exploration. When he opened the dome of his observatory and took his seat at the eyepiece of his spectroscope, he entered on a perilous journey to distant worlds where only ingenuity in reading and understanding the records of his instruments could save him from wrong conclusions, and where great perseverance was needed to try again and again to solve those riddles of the universe which would not easily give up their secrets. The major part of the Yerkes Observatory's contributions to stellar spectroscopy has been obtained in a similar spirit of exploration. Our procedure has usually been to examine with the utmost care all stellar spectrograms at our disposal and to try to detect those features which were not already explained by existing theories. Less often our search would be guided by previous theoretical considerations. Having found and described a hitherto unexplained phenomenon, we would next look for related data and then, if possible, measure some recognizable characteristic feature of the new phenomenon as a function of the related characteristic. Our purpose would always be to find a physical explanation. More often than not, the true explanation would escape us time and again, so that the work would have to be laid aside until an advance in a different field would make it tempting to try again.

We have always recognized the importance of long routine programs in astronomy, such as the construction of great catalogues of star positions, of magnitudes or of radial velocities; we have taken some part in programs of this kind, but we must now recognize that our contributions to such large-scale program work have been relatively slight. In stellar spectroscopy we are the successors of Huggins, not of Secchi with his famous catalogue of stellar spectra or of Vogel with his great and systematic work on stellar radial velocities.

When Hale prepared the plans for the Yerkes Observatory, he included in the specifications a stellar spectrograph for the 40-inch telescope. He was primarily interested in the physical study of the sun, but he undoubtedly wanted to supplement his solar investigations with the study of stars of similar characteristics. The outcome of this plan was an important memoir, *The spectra of stars of Secchi's fourth type*, which was published by him, in collaboration with F. Ellerman and J. A. Parkhurst, in 1904, as Part 5 of Volume II of the Publications of the Yerkes Observatory.

Few astronomers nowadays are acquainted with the classification of stellar spectra by Angelo Secchi, who recognized four main classes. Those having strong hydrogen lines were assigned to class I (now designated O, B, and A). Spectra with weak hydrogen and strong lines of elements like Fe I and Fe II, Ca I and Ca II, etc., were assigned to class II (now designated as F, G, and K). The red stars formed classes III (now designated as M) and IV (now designated as N). Hale had been much attracted by the early work of Huggins, Vogel, and others, which had seemed to indicate that Secchi's series of spectral classes represented an evolutionary sequence. The sun belongs to class II. Through the gradual loss of heat it would be expected to become redder. Will it ultimately become a star of class III or of class IV? It was not clear at that time whether classes III and IV represented successive stages of development or two parallel branches. All stars of class IV are fainter than magnitude 5, and little was known concerning their spectra. Hale and his collaborators decided to make use of the great light-gathering power of the 40-inch telescope to obtain spectra of reasonably good definition. The results of the observations, all of which were carried out between January 1898 and November 1902, were exceptionally valuable, and the illustrations which Hale included in his publication rank even now among the finest ever secured. For example, the authors succeeded in photographing the violet region of the spectrum in the neighborhood of Ca II 3933 in the star 19 Piscium—a feat which even today can be duplicated only with very few of the world's largest telescopes. The conclusion was that classes III and IV are parallel sequences, both leading back to stars like the sun. This conclusion has since been confirmed by many independent investigations.

The old Brashear spectrograph, with which Hale's work on the red stars had been carried out, was in many respects unsatisfactory. Its prism supports were not sufficiently rigid, so that small changes in the flexure of the instrument would take place during the long exposures required for the fainter stars. There was no temperature control, and the dispersion of the prisms could change appreciably during a single exposure. Attempts to use this instrument for the determination of stellar radial velocities were unsuccessful. For ex-



George Ellery Hale, 1868–1938

Edwin Brant Frost, 1865–1935

ample, the well-known standard velocity star ϵ Leonis, as photographed on 17 occasions between February 11 and April 25, 1900, gave velocities ranging from −10 to +13 km./sec. This at first led to the belief that ϵ Leonis varied in radial velocity, but it was afterward shown that the star has an apparently constant radial velocity of about +5 km./sec. Hale pointed out that on many occasions the spectrograph gave excellent results, but it was not dependable and could not compete with instruments used at other observatories.

The greatest advance in perfecting the spectrographic equipment for radial-velocity work had been made a few years earlier by W. W. Campbell at the Lick Observatory. His famous Mills spectrograph was capable of producing spectra with an average dispersion of the order of 10 A./mm. Stars with sharp and strong lines whose laboratory wave lengths were accurately known could be measured with a precision of the order of ±0.1 km./sec. This was an enormous gain over the earlier work of Vogel and Scheiner at Potsdam. It has only recently been surpassed by measurements at the Mount Wilson Observatory on photographs taken with the large, stationary spectrograph at the coudé focus of the 100-inch telescope.

In 1898 Hale obtained a grant from Miss Catherine Bruce, of New York, which enabled him to appoint E. B. Frost, of Dartmouth College, as professor of astrophysics at the Yerkes Observatory and to furnish sufficient funds for the construction of a new spectrograph for accurate radial-velocity work. The instrument made use of three large prisms of Jena flintglass, figured by Brashear in Pittsburgh. The collimator, having an aperture of 51 mm. and a focal length of 1 m., was specially designed by Prof. Hastings to be used in connection with a correcting lens, placed in the cone of rays from the 40-inch objective, in front of the slit, whose purpose it was to convert the visually corrected telescope into one with a color curve having a flat portion in the violet region of the spectrum. Two cameras were provided having focal lengths of 449 and 607 mm., respectively. The mechanical supports were built of strongly reinforced steel, and, following the example of the Lick Observatory, the spectrograph was attached to the telescope near the center of gravity of the former—a procedure which greatly reduced the danger of flexure.

The Bruce spectrograph was placed in operation late in 1901. It has remained in constant use for 46 years, but the optical parts have been changed from time to time, and provisions were added to use it with either one or two prisms. The linear dispersion on the plate is 10 A./mm. at λ 4,500 when used with three prisms and with the longer camera. Tests by Frost and Adams indicated that the precision of their radial-velocity measurements was quite similar to that obtained by Campbell at the Lick Observatory.

Frost's first work with the Bruce spectrograph dealt with the motions of the helium stars. Because many bright representatives of this class are located in the constellation Orion, they were designated by Frost as stars of the Orion type. Perhaps the fact that Hale was concentrating upon stars at the end of the evolutionary sequence, as conceived by Huggins and Vogel, induced Frost to give his attention to those objects which "seem unquestionably to occupy a position very early in the scale of evolution." In the half century which has elapsed since then, our ideas of stellar evolution have undergone many changes. We no longer think of the helium stars as forming the beginning of the cycle and the red stars as forming the end. But in many respects these two groups are still recognized as extreme opposites in temperature and in other physical characteristics.

Together with W. S. Adams, Frost published a paper under the title "Radial Velocities of Twenty Stars Having Spectra of the Orion Type." Although the number of stars was not sufficient to make a solution for the motion of the sun in interstellar space, "the distribution of positive and negative velocities shows clearly the direction of the motion of the sun in space." The average motion of a helium star was found to be surprisingly small—only 7.0 km./sec. It was already known from the work of Campbell and others that the average velocity of the cooler stars is considerably larger. Thus, Frost and Adams brought out the significant fact that the average motions of the stars are not the same for all spectral types. This result has been of fundamental importance in all later investigations concerning the dynamics of the stellar system.

A very puzzling result was stated by the authors in the following short sentence: "... if the sign be regarded, the mean becomes +4.6 km./sec." In other words, after the component of the solar motion had been subtracted from the measured radial velocities, the mean velocity was not zero, or close to zero, but was of the same order of magnitude as the mean velocity taken without regard to sign. The authors had thus, for the first time, recorded the famous K-effect in the motions of the helium stars, which, literally interpreted, means that the system of these stars, as a whole, expands with a velocity of 4.6 km./sec.

In 1910 Frost, in collaboration with J. C. Kapteyn returned to the question of the mean motion of the helium stars. After having discussed the solar motion from the large amount of material collected by Frost, the authors remark:

> ... meanwhile our numbers bring out a somewhat unexpected fact, namely, that the velocity of the sun relative to the stars near the apex is found to be very different from that relative to the stars near the antapex. To show this more clearly, a separate solution was made for the stars for which $\lambda < 90°$ and for which $\lambda > 90°$ (λ is the angular distance of a star from the apex, that is, from the point in the sky towards which the

solar system is moving). We thus find:

Near apex $v = 18.38 \pm 1.40$ km./sec. from 32 stars
Near antapex $v = 28.38 \pm 1.36$ km./sec. from 29 stars
Simple mean $v = 23.38$ ..... from 61 stars

The difference is very considerable and cannot well be attributed to accidental error alone.

It would seem that in the direction in which we are moving we are approaching the stars less rapidly than we are receding from the stars located in the opposite direction. This would not be possible if the stars were, on the average, stationary. They must have a systematic motion, and this can best be described as a general expansion in all directions. The nature of this expansion has been the subject of many later investigations. Frost, himself, spent much time and effort in proving that it could not be due to errors in the assumed stellar wave lengths, which were then known with insufficient accuracy. Later workers attributed it to a spurious effect caused by a cluster of helium stars in the Scorpius-Centaurus region, which all move in the same direction. Still others have thought of a gravitational red-shift, a phenomenon which may well be present in the most massive stars of very high temperature whose radii are not particularly large. The problem which was opened by Frost and Kapteyn is still unsolved.

In the course of Frost's radial-velocity work on the stars of early spectral type, many new binaries were discovered. These objects show variable radial velocities, and sometimes their lines are double—corresponding to the opposite motions of the components in a close double-star system. The pages of the *Astrophysical Journal* were virtually swamped with announcements of new binaries. Their number grew so rapidly that Frost was, at times, concerned over the question whether enough stars of constant velocity would be left to provide sufficient material for the statistical study of the motions of the helium and hydrogen stars. He and his associates, therefore, began the laborious task of determining the orbits of some of these binaries. Only in this manner could the average systemic velocity of a close double star be determined.

On May 14, 1902, Frost made a discovery of great importance. On that particular night he obtained two spectrograms of the bright helium star, β Cephei. He had observed it on many previous occasions and had found the velocity to vary as in a spectroscopic binary. But all efforts to find a period within the usual range of a few days to a few weeks had failed. He states in his first announcement concerning β Cephei:

> We had assumed from the first plates that the period would be rather long, but a suspicion to the contrary led me to take two plates on the night of May 14, and during the interval of five and one half hours the velocity changed 14 km., or nearly half of the whole range so far observed.

Such rapid variations in velocity were a sensation in 1902, and Frost diligently continued his observations. Four years later he announced that the period is $4^h34^m11^s$, and that the velocity curve is nearly symmetrical, with a range of 34 km./sec. He tried to determine a set of orbital elements, in the conventional manner, and found that the radius of the projected orbit would be unbelievably small—only 45,000 km. Later investigations at the Yerkes Observatory, including one completed in 1947 by Miss Nancy Roman, show that β Cephei is not a real binary, but a star of other and, in many respects, unique physical properties. We still know little concerning the cause of the variations in radial velocity; perhaps they are produced by some kind of pulsations, as in the Cepheid variables. Another interesting representative of this class of stars, β Canis Majoris, has been investigated by Swings and the writer and more recently by Miss A. Underhill. It shows remarkable, and as yet unexplained, periodic variations in the profiles of the absorption lines (first discovered at the Lick Observatory).

The last years of Frost's administration were clouded by his blindness. He lost the sight of one eye, through the loosening of the retina, while working with the 40-inch telescope. A rapidly growing cataract in the other eye in 1921 ended his scientific work. He retained the directorship until 1932, but he was no longer able to take an active part in the research work of the Observatory.

The original equipment of the Observatory was unquestionably the best that could be obtained at that time. But severe financial restrictions throughout most of Hale's and all of Frost's administrations made it impossible to maintain the equipment on the high level that was required to meet the competition of other institutions. The Yerkes Observatory gradually fell behind, and the work slowly assumed a more routine character. It was at this stage that, through the initiative of President R. M. Hutchins, a new era of development and expansion was started. In 1932 Frost retired, and the writer was appointed to succeed him as the director. At the same time a contract was signed, binding the University of Texas and the University of Chicago for 30 years in the joint operation of a new observatory, to be built in the Davis Mountains of western Texas from the W. J. McDonald bequest to the University of Texas. The new observatory, equipped with an excellent 82-inch reflector and with up-to-date spectrographic equipment, was completed in 1939. Since then, most of the results in stellar spectroscopy have come from material secured with the McDonald telescope. But it is not possible to distinguish between Yerkes and McDonald contributions. They are closely interwoven and should be regarded as the work of a single group of scientists.

Through the perseverance of many careful observers at the 40-inch telescope there had been gradually accu-

mulated, by about 1925, a fine collection of approximately 10,000 photographs of the spectra of nearly 1,000 different stars. Frost had intended to use this material for the determination of the motions of the stars in the line of sight. The spectra of the stars were flanked on both sides by the spectra of a laboratory source, such as that of the electric spark between iron or titanium terminals. The photographs could then be placed in a measuring machine, and the astronomer could determine the slight "Doppler shifts" of the lines of the star as measured with reference to the lines of the comparison source. This work was carried out in two stages: in 1926 we published the results for 360 stars of the helium type (now designated as class B); in 1929, the velocities of 500 hydrogen-type stars (now designated as class A).

More important was the opportunity which the collection of spectrum photographs offered for the study of the intensities and profiles of the lines. Most people have only a hazy idea of the appearance of the absorption lines in a stellar spectrum. Since the spectrum is produced by illuminating a narrow metal slit with the light of the star, we expect to find a continuous band of colored light, crossed by sharp, black lines whose profiles are faithful images of the slit and whose locations on the continuous spectrum correspond to those shades of color which are absorbed by the atoms in the atmosphere of the star. Such a spectrum is actually observed when we examine the light of the sun with a prism or diffraction grating. But not all stars have such spectra. Many have broad and hazy features in the place of the sharp Fraunhofer lines of the sun, and frequently they are not at all black, even near their centers, but are visible only as very slight depressions of intensity in the continuous spectrum.

In the course of my work on the measurement of the Doppler shifts of these hazy features, I was seriously bothered by the question of whether we could really trust the settings which I was making upon the geometrical centers of the broad lines. The results were plausible, but I would have been better satisfied if I could show that the cause of broadening acted symmetrically toward the red and toward the violet sides of the spectrum. Little was then known about the broadening of spectral lines in the laboratory, and next to nothing about their broadening in the stars.

The first task was to examine all cases of broadened absorption lines in order to determine, if possible, whether they originated from one cause or from several. It was at once clear that very strong lines—those which presumably were produced by large concentrations of atoms—are always broad. Such are, for example, the famous calcium lines of the sun, *H* and *K*. But there are many stars in which all lines, both faint and strong, appear broad. In other stars precisely the same lines are sharp and narrow. This phenomenon was highly intriguing. We tried at first to determine whether the stars with broad lines differed systematically in their other characteristics from those with sharp lines, but in nearly all respects the two groups were identical. We suspected a tendency of the broad-lined stars of the hydrogen type (class A) to be intrinsically less luminous than those with narrow lines, but before our discussion was completed, the same result was announced by Adams and Joy in their paper on the absolute-magnitude difference between stars with nebulous and stars with sharp lines. But the phenomenon did not suggest a physical cause of the line broadening, and it has since been shown to be caused, at least in part, by a systematic difference in the classification of the spectra.

The solution to our problem came from an examination of close spectroscopic double stars. Those with very short periods (of the order of one day) always had broad lines, while those of longer periods usually had much narrower lines. The short-period systems undoubtedly consisted of two stars almost in contact. Tidal forces would compel them to rotate as one solid body: the periods of rotation and revolution would be the same. Hence, the broadening should be due to rapid axial rotation. This result was later confirmed in many different ways, and, by analogy, we concluded that single stars also occasionally rotate with enormous speeds. The highest velocity at the equator is of the order of 300 km./sec.; that of the sun, only 2 km./sec.

The discovery of stellar rotation opened the way to other studies. On the one side, it led to studies of the distribution of rotational velocities and their bearing upon the old problems of the origin of double stars and planetary systems. On the other, it raised the question: Are there other spectroscopic phenomena which are correlated with that of axial rotation? One interesting correlation was found at once: the widths of the hydrogen emission lines observed in a small fraction of the helium and hydrogen stars are correlated with the rotational velocities determined from the absorption lines. The conclusion was simple: these stars are surrounded by nebulous envelopes of luminous hydrogen which revolve around them. When the axis is perpendicular to the line of sight, the emission lines and absorption lines are broad; when it is in the line of sight, both types of lines are narrow. However, the absorption lines can be narrow not only because the axis is in the line of sight but also because the star has actually a slow rotation. Such stars have no emission lines. The existence of the radiating nebula depends upon rapid rotation, it being somehow produced as a result of this—most probably through some kind of equatorial escape of gases from the rapidly rotating star. Sometimes, when we observe a rapidly rotating star whose axis is very nearly perpendicular to the line of sight, a thin, but radially extended, gaseous ring is formed which produces a series of very narrow and sharp absorption lines.

Gradually we eliminated those spectroscopic phenom-

ena which are caused by stellar rotation. After this was done, it appeared that there were many stars of class B in which some helium lines were broad and hazy, while others were sharp and narrow. The lines were all relatively weak; hence, the broadening was not that produced by large concentrations of atoms. An examination of laboratory data on the Stark effect showed that all those lines whose Stark splitting in an electric field is pronounced are broad in the helium stars. This type of broadening is well known to physicists and is ascribed by them to the perturbing action which neighboring charged particles—electrons or ions—produce upon the radiating atoms of helium. Such an effect should be large when the pressure is large, because then the perturbing particles are close to the radiating atoms. Upon this theoretical prediction we built a method for determining the pressure in stellar atmospheres. From these we could easily find the luminosities and could decide from the appearance of the helium lines whether a star is a supergiant or one of more moderate luminosity.

There was an interesting consequence of this work on the Stark effect. In the laboratory the presence of electric fields facilitates the appearance of helium lines which are normally forbidden by the selection rules. These lines were actually found in several dwarf stars such as γ Pegasi and τ Scorpii. But another prediction of the Stark effect could not be verified: electrical fields are known in the laboratory to shift some helium lines toward the red side and others toward the violet side of the spectrum. The broadening should thus be one-sided; the lines should be unsymmetrical and their measured positions should give slightly erroneous wave lengths. We noticed early in our investigations that the broadened helium lines were essentially symmetrical, so that any excess of broadening on one side over that on the other could only be an effect of the second order. Many years ago I suggested that this peculiar discrepancy between observation and the statistical theory of Stark broadening is caused by the collisions of particles and radiating helium atoms. The theory of collisional broadening has in the meantime been developed by physicists. But the exact application to stellar atmospheres was lacking until Chandrasekhar made an important theoretical advance which enabled Mrs. M. Kiess-Krogdahl to explain not only the symmetrical appearance of the lines but also their observed profiles and equivalent widths.

Our next concern was that of the strange, broad but often very deep lines in supergiants and a few peculiar stars such as 48 Librae. Rotationally broadened lines have shallow central depressions; lines broadened by large concentrations of atoms (radiation-damping), by Stark effect, or by collisions, all have characteristic wings. The lines in supergiants have bell-shaped profiles, with relatively steep edges. Thermal motions cannot explain them, because the lines are much too broad for the temperatures known to exist in the reversing layers. Our study was complicated by the fact that the resolving power of astronomical spectrographs is not sufficient to bring out this type of broadening except in very few bright stars. After several years of unsuccessful efforts, Elvey and I finally found the explanation: the atmospheres of many supergiant stars are not quiescent, but show strong, turbulent currents, up and down, so that the observed line-profiles have approximately the shape of a Gauss curve, the motions being distributed more or less in a random manner. There have been numerous investigations of this phenomenon since our announcement of it in 1934. One of the most significant was by J. L. Greenstein, who showed that there exist in the observed profiles appreciable departures from the simple Gauss curve. In a few supergiants (α Cygni) and stars with very extended atmospheres (17 Leporis) there is a tendency for the lines to show profiles with two minima of intensity, sometimes of unequal depth. This would suggest that the motions are predominantly in two streams: one rising in the atmosphere, and the other descending. But the line-profiles show that the two streams must be thought of as consisting of turbulent cells of dimensions which are small, relative to the height of the star's atmosphere. There has as yet been found no direct connection between the phenomena of turbulence in stars and in the earth's atmosphere, but the possibility of such a connection is not excluded.

The most recent advance in this field resulted from a comparison of measurements by Miss H. Steel in the spectrum of δ Canis Majoris with others made by me. The conclusion was that the turbulent velocity is a function of height in the reversing layer, increasing with the latter.

The problem of the central intensities of stellar absorption lines has been the subject of several Yerkes investigations, notably by Greenstein. Stars with large rotations or with other forms of mechanical Doppler broadening, such as expansion in novae or nova-like stars, were, of course, excluded. The hot stars have relatively shallow lines, even in supergiants, but Greenstein pointed out that they are not as shallow as theory would have led him to expect.

In a way, our studies of stellar line-profiles were all preparations for the important task of determining the abundances of the chemical elements in the atmospheres of the stars. There are some reasons to believe that these abundances are not the same in all stars, and much of the evidence comes from the Yerkes and McDonald Observatories. Thus, υ Sagittarii, according to Greenstein, has a low abundance of *H* and a high abundance of *He*, while Popper has found a helium star without any lines of *H* whatever. Astronomers at other observatories have been led to similar conclusions. All of these results depend upon our ability to derive the number of

absorbing atoms per cubic centimeter from the profile of an absorption line.

The question of the abundances of the chemical elements in the universe constitutes one of the most fundamental problems of all physical science, and it is receiving increased attention at the Yerkes and McDonald Observatories. It is an extremely difficult problem, however, and astrophysics is full of the graves of premature and insufficiently founded theories and observational conclusions. Among the most convincing data are recent results by G. Herzberg from McDonald spectrograms on differences in abundance of the carbon isotopes in different stars. On the other hand, the writer has recently observed a close binary system (UX Monocerotis) in which the hydrogen absorption lines undergo periodic variations in intensity, so that at times they are almost invisible, while at others they are extremely strong. In this case, at least, it would be unsafe to attribute the variations to changes in abundance. It is certain that the real differences of chemical abundance are still, to a large extent, obscured by an unknown phenomenon which affects the line intensities. It will be necessary to identify this phenomenon and explain it before we can succeed with the abundance problem.

After we had derived a reasonably complete understanding of the profiles of stellar absorption lines, it was tempting to apply the new knowledge to certain mysterious stars which had puzzled astronomers since the days of Huggins. Foremost among them was the problem of ϵ Aurigae. A spectroscopic double star with a period of 27 years, this third-magnitude star shows only the lines of one component, and it is from the variable Doppler shift of these lines that the orbit could be determined. The plane of the orbit is in the line of sight, and once every 27 years the principal component of ϵ Aurigae is eclipsed by the other, invisible component. Spectroscopic double stars are not rare: several hundred have been discovered and critically analyzed. But ϵ Aurigae presented a puzzle which would not yield to the conventional methods of analysis. The eclipse was found to be total, so that the disk of the dark, invisible component completely covered that of the bright, visible star. Yet the spectral lines of the latter remained visible throughout the many months of totality. Most of them were greatly strengthened, appearing unsymmetrical during the partial phases of the eclipse. The light curve is of such a character, however, that the invisible, dark component can only be of much lower surface temperature than the principal component and consequently should have other absorption lines, namely, those which are characteristic of low temperature. Observations of ϵ Aurigae were started by Frost almost as soon as the Yerkes Observatory was opened. Several investigations of its spectrum were made at different times by Frost, Struve, and Elvey, but, while much valuable information was obtained, the cardinal question of why the lines of the bright component remained visible during totality remained unanswered. Finally, in 1937, armed with our new knowledge of line formation and with a new theory of the light curve, the problem was solved in a joint investigation by Kuiper, Struve, and B. Strömgren. The invisible, eclipsing star is incredibly large, its diameter being roughly similar to that of the orbit of Saturn. This enormous, cool supergiant is partly transparent, so that the light of the much smaller, bright component of the system shines through it. The asymmetries of the lines are produced by the gases of the cool supergiant, whose axial rotation produces a small relative displacement.

There remained one small but rather puzzling circumstance. The absorption effects in the cool supergiant which give rise to the observed asymmetries of the lines did not influence the strong magnesium line, Mg II 4481. This was unexpected, because from analogy with other, ordinary stellar spectra we should have believed this line to be affected quite as much as the numerous lines of Ti II, Fe II, etc. We started looking for other astronomical spectra which might show a similar weakness of the Mg II line. The outcome was a series of investigations, in which K. Wurm cooperated, on the suppression of lines with excited lower levels which are not metastable, when the field of radiation is of small density, but corresponds in distribution with wave length to a high temperature. The fundamental theoretical idea of this work goes back to a paper by S. Rosseland, published in 1926, and the phenomenon is usually described as that of diluted stellar radiation.

This phenomenon has proved to be a remarkably powerful tool in astrophysics. A layer of gas in front of a radiating stellar photosphere is, in effect, an absorbing screen which reduces the intensity of the transmitted beam in those wave lengths to which the atoms of the screen are tuned. An ordinary absorbing screen absorbs a fixed fraction of the incident light, whether it is placed close to the radiating source or close to the eye of the observer. But the absorbing source of magnesium atoms has the property of absorbing a larger fraction of the incident light if the atoms are near the surface of the star and a smaller fraction if they are far above the surface of the star. The suppression of the magnesium lines in ϵ Aurigae during the total eclipse means that the atoms are very far away from the source of light—the small, bright component which is being eclipsed. This is exactly what we had already deduced from the unsymmetrical lines of titanium, iron, etc. The latter are not sensitive to the dilution effect and always absorb the same fraction of the incident light, no matter what their distance is from the radiating source. If all absorbing atoms—those of magnesium, as well as those of titanium, iron, etc.—are located in the semitransparent, invisible supergiant component, we should be able to determine the distance between the two components

from the degree of suppression of the magnesium lines.

The most interesting applications of the theory of the dilution effect have been obtained in the case of the lines of helium. Some have lower levels which are metastable, while other, equally strong lines have excited lower levels which are not metastable but are connected with the ground level of the helium atom by very strong ultraviolet transitions. The former are not affected by the distance of the source, while the latter are suppressed unless the atoms are on the surface of the star itself.

We at once made use of this discovery. In several stars we found the sensitive helium lines to be suppressed by a factor of the order of 100, as compared to the normal intensities of these lines. Since the degree of suppression is proportional to the amount of radiant energy from the light source at the point where the helium atom is located, and since this is inversely proportional to the square of the distance from the star, we were able to conclude that the absorbing screen of helium atoms is located at an average distance of roughly 10 times the radius of the star itself.

This immediately led to the solution of another astronomical puzzle, namely, that of the famous eclipsing binary, β Lyrae. By a strange coincidence, the problem of β Lyrae was discussed at a conference of astronomers in connection with the dedication of the Yerkes Observatory in 1897, but the final solution came in a joint study by Kuiper and Struve in 1941. The system of two giant stars with almost touching surfaces generates a gaseous stream which flows from one component toward the other and is then split into two branches: the one flows around the cooler of the two components and returns ultimately to the place of origin; the other is forced by centrifugal action to leave the system and spirals rapidly outward into space. Gaseous streams produce remarkable absorption effects when observed in front of the luminous body of the hotter component of β Lyrae. When apparently projected upon empty space, they produce strong emission lines in the spectrum.

The recognition of gaseous streams in β Lyrae soon led to the discovery that many other binary systems possess similar streams. During the past four years much effort has been spent at McDonald and at Yerkes, at first in the study of the emission features produced by these streams, and more recently in the study of the corresponding absorption effects. This work is still in progress. A particularly interesting feature of these double-star spectra is the shape of the emission lines of hydrogen, consisting of two separate peaks. As the invisible component of the double star begins to eclipse the brighter component, we observe at first the disappearance of the violet emission peak; then, during total eclipse we often fail to see any trace of emission, while after totality we observe the appearance of the violet peak and the disappearance of the red peak. The emitting atoms of hydrogen form a ring around the bright double-star component which revolves around the latter in the same direction as the orbital revolution.

In 1939, P. Swings came to the Observatory from Belgium to collaborate in the study of another class of peculiar stellar spectra. He intended to remain for one year, but the war intervened and he remained until the middle of 1943. During this interval we devoted most of our attention to an interesting group of objects—those whose spectra have sharp and narrow emission lines of highly-ionized atoms, often including the forbidden nebular types of radiation. Due to Swings' experience in the spectroscopic analysis of laboratory sources we were able to record and identify numerous previously unknown emission lines. Many new results were obtained, and the previously proposed hypothesis of the binary nature of these objects was greatly strengthened.

Another puzzling group of objects was attacked by Swings and Struve with the large coudé spectrograph in a study of α Canum Venaticorum. This star has at times very strong lines of Eu II, Gd II, and other rare earths, but the intensities are variable in a period of about 5 days, so that at certain other times the rare earths are absent or very weak. An exhaustive investigation gave a good description of the phenomena, but served only to eliminate such simple explanations as a periodic change in normal ionization conditions. We found a few suggestive relations, but were unable to account for the extraordinary variations. We next observed another star having variable lines, ϵ Ursae Majoris, but again there was no physical explanation. W. A. Hiltner made a study of β Coronae Borealis in which the rare-earth lines are also unusually strong but in which there are no periodic variations in intensity; no clue to our problem was found. We have a large amount of observational facts for a few stars, and it is disconcerting that no theory is able to account for them. For further progress, more stars with variable lines must be found. This work of discovery was at first undertaken by W. W. Morgan, who in the early 1930's found several new representatives of this almost completely neglected class. A. J. Deutsch has greatly extended the work of discovery and has furnished us with a list of interesting objects and their periods. Whether we now have a broad enough basis of observational data to insure success in our search for a physical theory remains to be seen.

During the past 15 years the 40-inch telescope has been used to good advantage for spectroscopic investigations with instruments of small dispersion. An *Atlas of stellar spectra* by Morgan, Keenan, and Kellman has become the accepted standard for the classification of stars according to their temperatures and pressures. Another atlas consisting of spectrophotometric tracings of coudé plates of 8 bright stars taken at the McDonald Observatory with dispersions between 2 and 14 A./mm. was prepared by Hiltner and Williams and published by the University of Michigan Press. This serves as

a valuable source for many astrophysical investigations.

Among the fuzzy-line stellar spectra of the helium type there were many which had sharp and exceedingly narrow lines of ionized calcium. These lines were known to Frost and his co-workers and aroused their interest because all other lines, such as those of He I, Si III, O II, etc., were uniformly broad and hazy. The problem of the sharp calcium lines was brought to a focus when in 1904 J. Hartmann, of Potsdam, announced that these lines remained stationary in the spectroscopic binary δ Orionis, whose other absorption lines showed the characteristic periodic variation in radial velocity as the binary pursued its course along an orbit whose plane is approximately in the line of sight. Hartmann had suggested that the stationary calcium lines are produced by a cloud of calcium atoms in interstellar space and have no relation to the binary system. But this revolutionary hypothesis was not accepted by other astronomers, and several investigations appeared (erroneously, as we now know) to show that the calcium atoms are distributed in the immediate neighborhood of the double-star components. The problem remained in this state until 1926, when A. S. Eddington, in his famous Bakerian Lecture of that year, presented strong theoretical arguments in favor of the existence of an exceedingly tenuous gaseous substratum in interstellar space. Eddington's work led to a simple prediction: the sharp calcium lines must be present in all distant stars, not only in spectroscopic binaries, and their absorption intensities must increase with the distances of the stars. The rich spectrographic material of the helium stars at the Yerkes Observatory offered a tempting invitation to test Eddington's hypothesis. We already knew that the helium stars have exceedingly high intrinsic luminosities—100 or even 1,000 times the candle power of the sun—so that for any given apparent magnitude an average helium star is from 10 to 30 times as far away as one of the solar type.

A preliminary study of the Yerkes collection gave a strong indication that the sharp calcium lines were indeed stronger in the more distant stars, but because of the limited light-gathering power of the Yerkes telescope the range in distance was not sufficiently large to place the result beyond all reasonable doubt. Our telescope was not big enough to photograph the spectra of the fainter and, hence, the more distant stars. In order to supplement the Yerkes material I obtained permission from W. S. Adams to spend several months at the Mount Wilson Observatory and to use the 60-inch reflecting telescope for the observation of the spectra of a selected list of faint helium stars, principally in the constellations Cepheus and Cygnus. I was also permitted to inspect the magnificent collections of stellar spectra at Victoria and at the Lick Observatory. The final result was a complete confirmation of Eddington's hypothesis: interstellar space contains a gaseous medium in which the ionized atoms of calcium—those which produce the observable lines *H* and *K* in the violet part of the spectrum—are distributed with a density so low that approximately one calcium ion is found in every 10^8 cc. of space. An interesting by-product of this work was a new method for the determination of the distances of the more remote stars in our galaxy from the measured intensities of the interstellar absorption lines.

In the meantime, principally through the research of H. N. Russell at Princeton, it had become amply clear that hydrogen forms by far the most abundant substance in the stars and nebulae. It seemed strange that the gaseous substratum in interstellar space should consist mostly of calcium. Was it not possible that, because of the very unusual conditions of extremely low pressure, high exciting temperature, and excessively low density of the exciting stellar radiation, the calcium lines would be placed at an advantage in producing absorption lines, while the hydrogen lines, even though produced by an exceedingly abundant species of atoms, would absorb so weakly that its lines would escape detection? There were theoretical reasons to suspect this; but how could we prove it? A simple computation showed that the interstellar hydrogen atoms, if really present in anything like the expected abundance, might produce a faint glow of radiation in the Milky Way, between the stars. There was, however, no spectrograph at our disposal sufficiently powerful to record this feeble hydrogen radiation.

We had a new Schmidt camera of the then unusual focal ratio f/1, which had been made for us by a Chicago amateur telescope maker, as well as a pair of excellent quartz prisms, but there was no suitable collimator. We decided to build a strange, new instrument at the McDonald Observatory. This has since been described in the astrophysical literature as a "nebular spectrograph." A small, clock-driven, equatorial mounting supports on one side a long, narrow, rectangular, plane piece of mirror which serves as the slit, and on the other side the Schmidt camera with quartz prisms, working as an objective-prism instrument. The reflection from the slit-mirror is directed upward along the polar axis to a stationary plane mirror placed higher up on the slope of our mountain. This circular mirror reflects the beam toward the camera, which is focused on the slit mirror at an effective distance of 150 feet. This instrument gave excellent results, and in a short time Elvey and I could announce the existence of vast regions of hydrogen radiation in the Milky Way. The average density of the interstellar hydrogen is about 1 atom/cc.

After the completion of the 82-inch telescope at McDonald in 1939, the nebular spectrograph was dismounted, and the work on interstellar hydrogen radiation was discontinued. In recent years J. L. Greenstein has used the large reflector in a study of the physical properties of those condensations of the interstellar medium which we know as gaseous nebulae.

Solar Research and Theoretical Astrophysics

S. Chandrasekhar

THE GREAT DISCOVERIES ASSOCIATED with the name of Hale—the spectroheliograph, the double reversal of the H and K lines of calcium in the spectrum of the flocculi, the magnetic field of sun spots and their laws of polarity, the general magnetic field of the sun—all belong to the earlier Kenwood period or the later Mount Wilson period. Hale's years at the Yerkes Observatory appear at this distance of time as an interim period of consolidation and study between years of great imagination and discovery. This may be disappointing to one who is looking back at the record of the Yerkes Observatory. Nevertheless, there is one romantic incident to which the University of Chicago (and the Yerkes Observatory) may lay lawful claim, namely, when Hale met the challenge of the spectroscopist, Carl Runge, that the bright yellow line discovered by the chemist, Sir William Ramsay, in the discharge through the gas occluded by the uranium mineral clevite cannot be identified with helium "unless the solar D_3 line were also double." On June 20, 1895, Hale succeeded in resolving the D_3 line of a bright solar prominence "into a delicate unequal pair" and "our possession of helium as a truly indigenous element was rendered incontrovertible."

Though the solar research carried out at Yerkes Observatory must take second place to the brilliance of the discoveries to be made only two or three years later at the Mount Wilson Observatory, the record of the Yerkes Observatory during the years between Kenwood and Mount Wilson is not insignificant. Indeed, Dr. Adams has written:

> As Hale moved onward to the wider field of work afforded by the Yerkes Observatory, he saw opportunities for extending his investigations with more powerful apparatus. A large spectroheliograph was one of the first requisites, and the Rumford spectroheliograph, when attached to the 40-inch refractor, has remained one of the most efficient instruments for certain types of solar research ever designed. With it dark hydrogen flocculi were discovered and the dark calcium markings which proved to be prominences seen in projection against the disk. The dispersion of the instrument was sufficient to make it possible to set the second slit upon different portions of the K line, and thus map the calcium flocculi at different levels through the solar atmosphere. A grating spectrograph supplemented the spectroheliograph, and with it Hale made the difficult visual discovery of the presence of the green carbon band in the spectrum of the chromosphere. He became fully aware at this time of the possibility of observing the chromospheric and much of the "flash" spectrum without an eclipse and in future years continued such work at Mount Wilson.
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> A strangely prophetic remark was made by Hale in an article published at the Yerkes Observatory in 1902: "The remarkable peculiarities of the spectra of sun spots seem to deserve more attention than they have hitherto received from spectroscopists." Widened lines in the spectra of spots had been observed visually by Young in 1872 and were studied systematically by the English astronomers Maunder, Cortie, and Lockyer. Hale made some attempts to photograph the spectrum of sun spots while at Kenwood Observatory, but his success was only partial because of the small size of the sun's image. With the larger image given by the 40-inch telescope at the Yerkes Observatory much better results were obtained, and not only were the widened lines measured but also many of the lines in a green band discovered by Maunder in 1880. Hale realized that for an adequate investigation of the spot spectrum greater linear scale in the spectrograph and a still larger image were needed. Accordingly he designed for the purpose a large spectrograph used in conjunction with a coelostat and long-focus concave mirror, thus planning to bring into regular astronomical use an instrument which had been relegated almost wholly to eclipse expeditions. This instrument finally took form in the Snow telescope with which in later years at Mount Wilson the first of the extensive sunspot investigations was begun.

After Hale's departure from the Yerkes Observatory, the Rumford spectroheliograph continued to be used systematically for many years. Of these later studies the most important are those of the late Philip Fox on "The Rotation Period of the Sun" and of Edison Pettit on "The Forms and Motions of Prominences." In the first of these two investigations Fox derived from some 4,000 measures of calcium flocculi on 285 plates the law of variation of the diurnal motion (ξ) in mean solar days at various heliographic latitudes (ϕ). He found that $\xi = 11°.584 + 2°.976 \cos^2\phi$. This law differs from those derived spectroscopically by Adams and presents a problem still awaiting solution.

In his investigations on the forms and motions of the solar prominences Pettit broke new ground, and his first study of the subject at the Yerkes Observatory still remains a classic. From this early study the remarkable fact already had emerged that the motion of a prominence measured along its trajectory is uniform, increasing suddenly at intervals as if by an impulse. This fact, confirmed by numerous later observations, still defies a satisfactory explanation.

After 1920 conventional solar research began to lag behind in the wake of the expanding interests in stellar astronomy and astrophysics, but occasionally some important investigations were carried out—for example, P. C. Keenan's careful photometry of the solar granulation. In one sense, however, interest in solar problems was never really lost. Indeed, as Hale has so often emphasized, "the student who would untangle the secrets

of the universe recognizes in the sun a typical star." This is particularly true of the student of theoretical astrophysics: for, a theory of stellar constitution, to be satisfactory, must first account for the solar energy, and a theory of stellar atmospheres, to be satisfactory, must first account for the solar spectrum. Thus, a problem which has been studied intensively during recent years relates to the continuous spectrum of the sun.

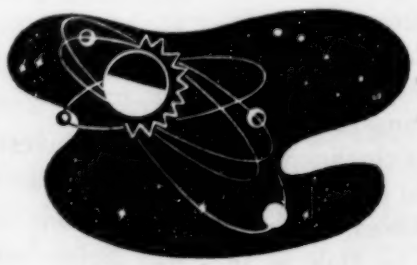
It has long been known that the observed laws of darkening and the distribution with wave length in the continuous spectrum of the sun imply a source of continuous absorption in the solar atmosphere which varies with wave length in the following manner: The absorption coefficient increases by a factor of the order of two from 4,000 to 9,000 A.; beyond 9,000 A. it decreases by about the same amount until we reach 16,000 A. in the infrared; and the indications are that as we go further into the infrared, the absorption coefficient again increases. For many years one of the principal problems of astrophysics was to determine the source of continuous absorption in the solar atmosphere which will show the behavior we have described. On the basis of theoretical work done at the Yerkes Observatory it has now been established beyond any possible doubt that the negative ions of hydrogen are responsible for the continuous absorption in the solar atmosphere from 4,000 to 20,000 A. This identification of the presence of the negative ion of hydrogen recalls to one the case of helium, whose presence in the solar atmosphere was known a quarter of a century before its terrestrial existence was established. In the case of the negative ion of hydrogen, its stable existence was first established by Bethe and Hylleraas on theoretical grounds, and it was only 15 years later that its physical existence as a free atom was established in the solar atmosphere.

The brief reference to the continuous spectrum of the sun which we have made reminds us of the important role which problems of radiative transfer have played in the theory of stellar atmospheres. Until recently the solutions even for the simplest problems were not available. But the studies undertaken at Yerkes Observatory during the past few years have provided *exact* solutions for a great variety of problems. From one point of view the most important of these advances relates to the solution of transfer problems in which the polarization characteristics of the radiation field are properly taken into account. The importance of such considerations has been recognized since 1871, when Lord Rayleigh accounted in a general way for the distribution and polarization of the sunlit sky. Nevertheless, even the basic equations for the problem were not written down before the problem arose in an astrophysical context. We may briefly explain the particular astrophysical problem which gave the final impetus to formulating and solving transfer problems in which the polarization characteristics of the radiation field are incorporated and properly allowed for.

From the investigations of J. L. Greenstein and others it appears that in the atmospheres of stars with surface temperatures exceeding 20,000° K the transfer of radiation must be controlled predominantly by the scattering by free electrons. According to J. J. Thomson's laws for this process, scattering by free electrons must result in the partial polarization of the scattered radiation. If our belief in the important role played by the Thomson scattering in the atmospheres of the hot stars is correct, we should expect that the radiation emergent from the atmospheres of such stars should be partially polarized. The question of the degree of polarization to be expected under such conditions therefore becomes a matter of exceptional astrophysical interest. But before we can answer this question, the relevant equations of transfer distinguishing the different states of polarization must be formulated and solved.

The problem of radiative transfer in an electron-scattering atmosphere has now been solved exactly, and the theory predicts a degree of polarization to the extent of 12 per cent at the limb. It is apparent that if the predicted effect is present, the most favorable conditions under which the phenomenon could be observed are during phases close to the primary minimum in an eclipsing binary, one component of which is an early-type star. It is gratifying to be able to record that careful polarization measurements on RY Persei by A. W. Hiltner at the 40-inch telescope indicate that the effect of the predicted amount is very probably present.

The foregoing brief sketch is intended merely to give an impression of the kind of problems in solar and theoretical astrophysics which have been studied at the Yerkes Observatory. But it serves to underline a fact which Hale often emphasized, namely, that there is "no essential difference between the attitudes of a physicist and an astronomer."



The Spectroscopic Laboratory

G. Herzberg

IN AN ADDRESS TO THE ROYAL INSTITUtion in May 1909, George E. Hale spoke as follows:

It is customary to distinguish sharply between observational and experimental sciences, including astronomy in the former. In physics or chemistry the investigator has the immense advantage of being able to control the conditions under which his observations are made. The astronomer, on the other hand, must be content to observe the phenomena presented to him by the heavenly bodies and interpret them as best he may. I wish to emphasize the fact, however, that the distinction between these two methods of research is not so fundamental as it may at first sight appear. In 1860 a laboratory in which experiments were conducted for the interpretation of astronomical observations was established by Sir William Huggins on Upper Tulse Hill. The advantage of imitating celestial phenomena under laboratory conditions was thus appreciated half a century ago. I shall indicate later how important a part such a laboratory plays in the work of the Mount Wilson Solar Observatory. I shall also show that in other ways the astronomer may advantageously follow the physicist, particularly in the choice of observational methods and in the design of instruments of research.

Hale realized, perhaps more clearly than anyone else of his time, the importance of laboratory investigations for the interpretation of celestial spectra and other astrophysical problems. Therefore, he had provided considerable space for laboratory work in his plans for Yerkes Observatory. There was a spectroscopic laboratory, a chemical laboratory, a physical laboratory, a galvanometer room, a concave grating room, and other laboratory rooms, making up fully 25 per cent of all the space, other than the domes, available at that time. In the heliostat room Hale made provision for drying the air to make possible the use of rock salt prisms and lenses, obviously having in mind plans for investigating the infrared solar spectrum, and he emphasizes that "the entire distance (175 ft.) between the heliostat room and the wall of the great tower is available for use with apparatus containing mirrors or lenses of great focal length, etc."

Needless to say, Hale made full and frequent use of these laboratory facilities. Mention should perhaps be made of his extensive research in collaboration with N. A. Kent on "The Spectrum of the High Potential Discharge Between Metallic Electrodes in Liquids and in Gases at High Pressures" (*Publ. Yerkes Observ.*, 1907, III, 29), which led to abandonment of the pressure theory of novae advanced by Wilsing and which at the same time represented one of the first systematic investigations of the effects of pressure and other discharge conditions on the spectrum produced.

With Hale's departure from Yerkes Observatory, interest in laboratory investigations gradually subsided, and with the increase in staff the various laboratory rooms were gradually assigned to offices and other purposes. This development was compensated in a way by the growing interest of physicists at the beginning of this century in laboratory spectroscopy and by the rapid developments in the interpretation of spectra with the aid of quantum theory. Great strides were made in the advancement of our knowledge of the line spectra of individual elements and of the band spectra of many molecules. The profound influence of these developments on astrophysics hardly needs special emphasis.

Toward the end of the fourth decade of this century, when many of the fundamental problems of atomic and molecular spectroscopy had been solved, the interest of the physicist in spectroscopy lessened, and his attention turned more and more to nuclear physics. At present, very few physics departments are left in this country in which research in spectroscopy of the type of interest to the astronomers is actively prosecuted. On the other hand, while some problems, such as the identification of the nebular lines and the coronal lines, have been solved, others have remained unsolved, and new ones constantly appear which might be solved by cooperation of the astrophysicist and laboratory spectroscopist. This is particularly true in the field of molecular spectra, whose application to astrophysical problems has proved fruitful in recent years. It was with these points in mind that the administration of Yerkes Observatory asked the writer two years ago to join the staff and re-establish a spectroscopic laboratory.

Since the rooms originally assigned by Hale for laboratory work were no longer available, the new laboratory was set up in the basement between the two small domes. A 21-foot grating in a modified Eagle mounting was installed. The location of this instrument was so chosen that, with the aid of a heliostat and one additional mirror, the solar spectrum can be studied and a comparison with laboratory spectra thus easily made. The grating, supplied by R. W. Wood, has an excellent concentration in the first order of 11,000 A. or second order of 5,500 A., etc. In addition, a medium Hilger quartz spectrograph was purchased for work with intermediate dispersion. More recently, the photoelectric infrared spectrometer built by Dr. Kuiper for work at McDonald Observatory has also been used in the laboratory.

A considerable part of the activity of the laboratory at present is devoted to the investigation of molecular gases with long absorbing paths, particularly for comparison with the spectra of planets. As is well known, the spec-

trum of Venus in the red and near infrared shows absorption bands of carbon dioxide (CO_2), while the spectra of Jupiter, Saturn, Uranus, and Neptune show strong bands of methane (CH_4), and Jupiter, in addition, shows ammonia (NH_3). In the laboratory these absorption bands can be obtained only with very long absorbing paths, indicating that large quantities of the respective gases are present in the planetary atmospheres. In all previous laboratory work (with the exception of NH_3), in order to duplicate the planetary spectra, very high pressures had to be used. These broaden the lines to such an extent that much or all of the fine structure of the bands is lost. For a more detailed comparison it appears necessary to use much longer paths than heretofore, so that the planetary spectra can be reproduced at comparable pressures. Indeed, it should be possible in this way to obtain not only the total amounts of these gases present above the reflecting layers of the planets but also at least rough estimates of pressures and temperatures.

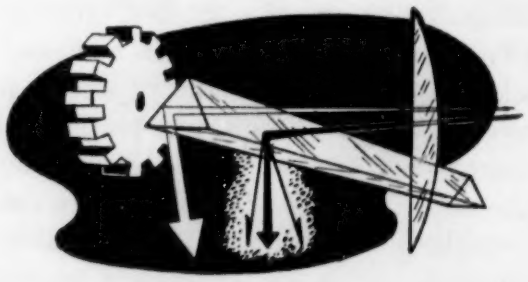
For these investigations a long iron pipe, 10 inches in diameter and 75 feet long, was installed running through almost the whole length of the basement. By means of mirrors according to a scheme devised by J. U. White (*J. opt. Soc.*, 1942, **32,** 285), light of a continuous spectrum was made to traverse this pipe up to 100 times before entering the spectrograph. Thus, an absorbing path of up to 7,500 feet, or 2,200 m., has been obtained. In this way it has been possible to reproduce at atmospheric pressure, and even at lower pressures, the CO_2 bands observed in Venus, with their fine structure preserved. The laboratory intensity is still appreciably less than that observed in Venus, indicating an amount of CO_2 in Venus of more than 1,100 m. atm. At the same time it is possible to say that the pressure in the Venus atmosphere (above the reflecting layer) is less than 1 atm. and that the temperature is near room temperature. These preliminary results will have to be checked and extended, particularly to include CH_4. Moreover, the spectral region 1–2.5 μ will be investigated jointly with Dr. Kuiper with the aid of his infrared spectrometer and for the purpose of comparison with the planetary spectra which he has obtained in this region with the same instrument.

The same long optical path is also being used for the study of the ultraviolet absorption of atmospheric and other gases. A number of years ago an extremely weak system of absorption bands of oxygen with adjoining continuum was found in the near ultraviolet (from 2,600 A. to shorter wave lengths). This band system has now been obtained with adequate intensity of absorption and under high resolution, so that a fine structure analysis will be possible. Absorption in the adjoining continuum leads to dissociation of O_2 into O + O. It is probable that this process is responsible for the formation of the ozone layer. In addition, it may be noted that it is this absorption that accounts for the fact that the solar spectrum does not reappear between 2,200 and 2,000 A., where the ozone absorption is negligible. Finally, it is likely that the same band system accounts for a number of prominent and otherwise unidentified features of the spectrum of the night sky (P. Swings. *Ap. J.*, 1943, **97,** 72).

Another field in which work has been taken up in the laboratory is the study of molecular spectra occurring in late-type stars. A system of green bands first found in certain N stars by Sanford is as yet unidentified (see A. McKellar. *Roy. astr. Soc. Canada*, 1947, **41,** 147). A considerable amount of work was done by J. Phillips to duplicate this spectrum in the laboratory, as yet without success. Prominent features of all M stars are the bands of TiO, while in S stars the bands of ZrO predominate. Some laboratory work on these molecules has been done in the past, but much more work remains to be done, particularly if one wants to obtain reliable values of the dissociation energies of these molecules.

Reliable values of dissociation energies are lacking also for a number of other astrophysically important molecules, notably carbon monoxide (CO). Work is in progress in the laboratory by K. N. Rao for the purpose of obtaining an unambiguous determination of the heat of dissociation of CO.

For a theoretical discussion of the dissociation equilibrium in stellar atmospheres a knowledge of the dissociation energies of all molecules likely to be formed is necessary. A number of dissociation energies used in earlier work in this field are now known to be grossly in error. Once their exact values have been established, a rediscussion of this field might be in order.

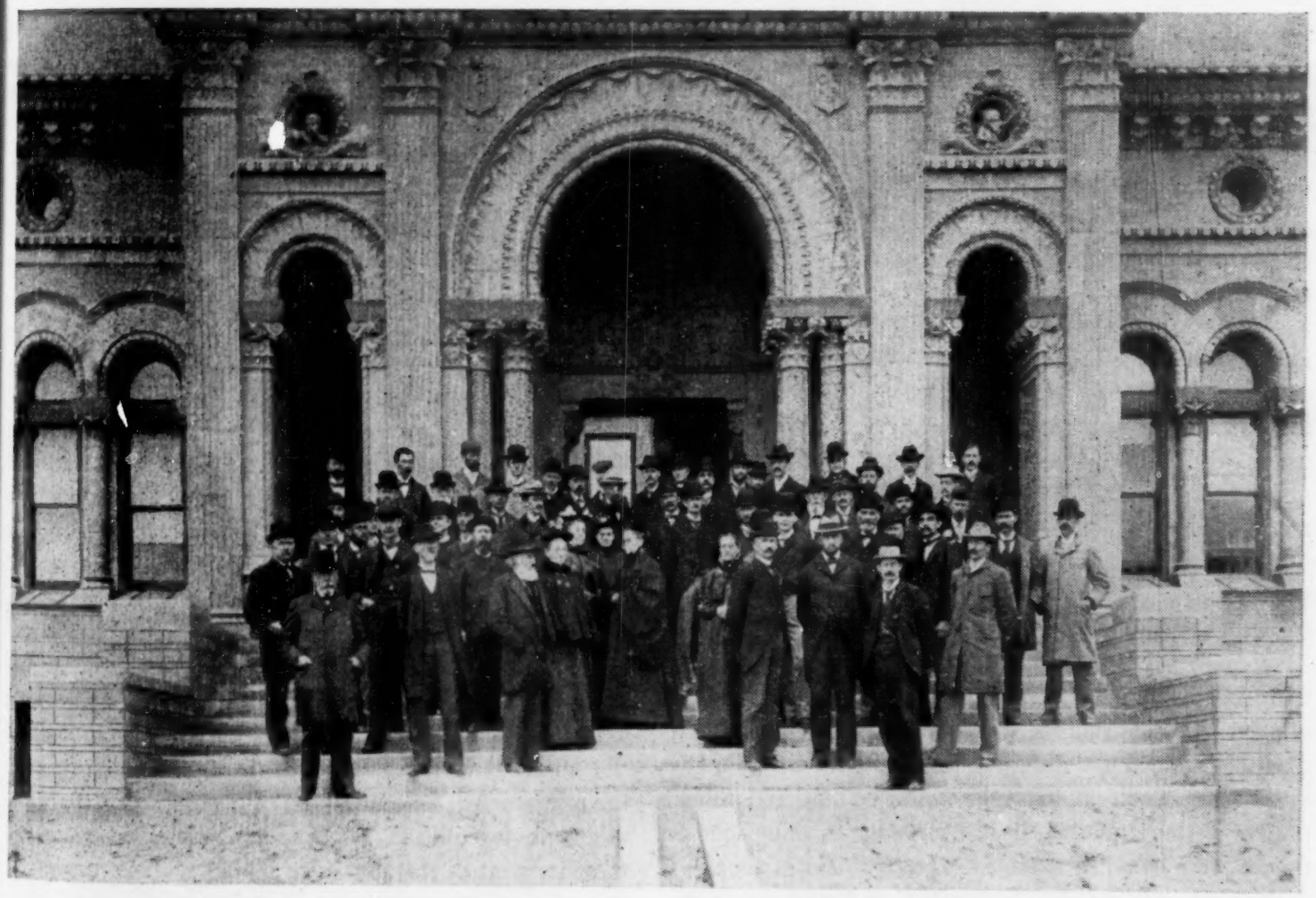


The Yerkes Observatory: Past, Present, and Future

Otto Struve

THE YERKES OBSERVATORY WAS planned and organized by George E. Hale who, at the age of 24, had been appointed professor of astronomy at the new and struggling University of Chicago. Through the generosity of Charles T. Yerkes, traction magnate of Chicago, two 40-inch glass disks were purchased from the firm of Mantois in Paris, and a contract was signed with Alvan G. Clark, of Cambridgeport, Massachusetts, for the work of grinding and polishing. The mounting for the large telescope was made by the Warner and Swasey Company, Cleveland, Ohio, and was exhibited at the Columbian Exposition in Chicago in 1893. The building of the Observatory, on the north shore of Lake Geneva, in Williams Bay, Wisconsin, was started in 1895. On May 19, 1897, the objective for the large telescope arrived in Williams Bay. Two days later, after it had been mounted in the 62-foot tube, astronomical observations were commenced by G. E. Hale, E. E. Barnard, and S. W. Burnham. The quality of the star images was found to be exceedingly fine, and the great light-gathering power of the lens was so remarkable that Barnard remarked that he had never before seen so clearly the faint stars of the cluster in Hercules.

The Observatory was dedicated on October 21, 1897, in the presence of a large gathering of astronomers and guests. Henry Crew, of Northwestern University, one of



Group photographed at the dedication of the Yerkes Observatory, October 20, 1897: E. E. Barnard, C. H. Rockwell, George F. Hull, —— Colton (?), Kurt Laves, Frank W. Very, E. B. Frost, Henry M. Paul, Ernest F. Nichols, F. R. Moulton, Ephraim Miller, Father John Hedrick, John M. Van Vleck, Milton Updegraff, Wm. R. Brooks, F. L. O. Wadsworth, H. C. Lord, F. H. Seares, George W. Hough, W. H. Collins, Caroline E. Furness, Mrs. Pickering, Mrs. Hale, Miss Cunningham, Alva A. Lyon, Carl A. R. Lundin, J. A. Parkhurst, J. A. Brashear, G. W. Ritchey, C. H. McLeod, Father J. G. Hagen, Charles L. Poor, J. K. Rees, Mary W. Whitney, F. P. Leavenworth, Henry S. Pritchett, J. E. Keeler, A. G. Stillhamer, Hugh L. Callendar, George W. Myers, C. L. Doolittle, E. C. Pickering, A. W. Quimby, Asaph Hall, Albert S. Flint, M. B. Snyder, W. W. Payne, Carl Runge, Winslow Upton, George Kathan, G. D. Swezey, George E. Hale, N. E. Bennett, George C. Mors, F. Ellerman, W. J. Humphreys, and Henry Crew.

the few surviving scientists who attended this celebration, has written as follows in a personal letter to the author:

> Hale's sound judgment and capacity for friendship were clearly shown by the first staff which he assembled at Williams Bay and by the group of productive scholars who "assisted" at the dedication of the Observatory. In the picture of this group, taken at the south entrance, one sees E. C. Pickering—long-time friend and adviser—standing in the front row between Keeler and Runge [right, extreme front]; and this in turn reminds one of that interesting remark which Runge made on that same day, in the meeting, when W. J. Humphreys had finished reading his report on the effect of pressure in displacing the lines of the arc-spectrum. Rising in his place, Runge said, "Mr. President, Nature is getting more and more disorderly every day!" and then proceeded to accept Humphreys' surprising results at full value.
>
> Returning to the group picture, the man in the front row with the white beard and with his hands in his pockets is that keen and doughty observer, G. W. Hough. At the extreme left, stands E. E. Barnard, at that time, the greatest of all living observers; while at the extreme rear of the picture, standing against one of the columns, wearing a cap and black beard, is F. L. D. Wadsworth—physicist, engineer, and astronomer—a man who helped Michelson and Hale more than the world will ever know.

Since the summer of 1897 the 40-inch telescope has been used regularly on all clear nights for the observation of stars, comets, and nebulae, and on many clear days for the observation of the sun. In 1897 it was the largest telescope of any kind then in actual operation, although Lord Rosse, and others, had already constructed and temporarily used reflecting telescopes of greater aperture. After 50 years the 40-inch telescope is still the largest *refractor* in the world. An attempt in France, many years ago, to construct an astronomical objective of more than 50 inches in diameter ended in failure. World War I interfered with the completion of a 41-inch refractor for an observatory in southern Russia, and the project was abandoned.

In certain types of astronomical observations the 40-inch refractor of the Yerkes Observatory still ranks at the top of the long list of telescopes. It is very little affected by changes in temperature, and it is never necessary to disturb it in its cell. In the most precise measurements of relative star positions it is often necessary to compare results obtained on different photographs taken many years apart. Such photographs would be rendered almost useless if the adjustments of the image-forming lens or mirror were changed between exposures. For example, a very slight change in the collimation of the objective can result in a small change of the character of the star's image of a point-source, like a star. This, in turn, would produce a spurious change in the distance between two stars of unequal brightness. Astronomers measure on their photographs displacements of less than 0.001 mm., corresponding to an angular distance of 0.01 second of arc in the focus of the 40-inch objective. Only the lenses of refracting telescopes have the required degree of stability and permanence. The large astronomical mirrors, many of which surpass the 40-inch objective in aperture, are subject to distortions causing astigmatism and to changes in adjustment when they are removed for silvering or aluminizing.

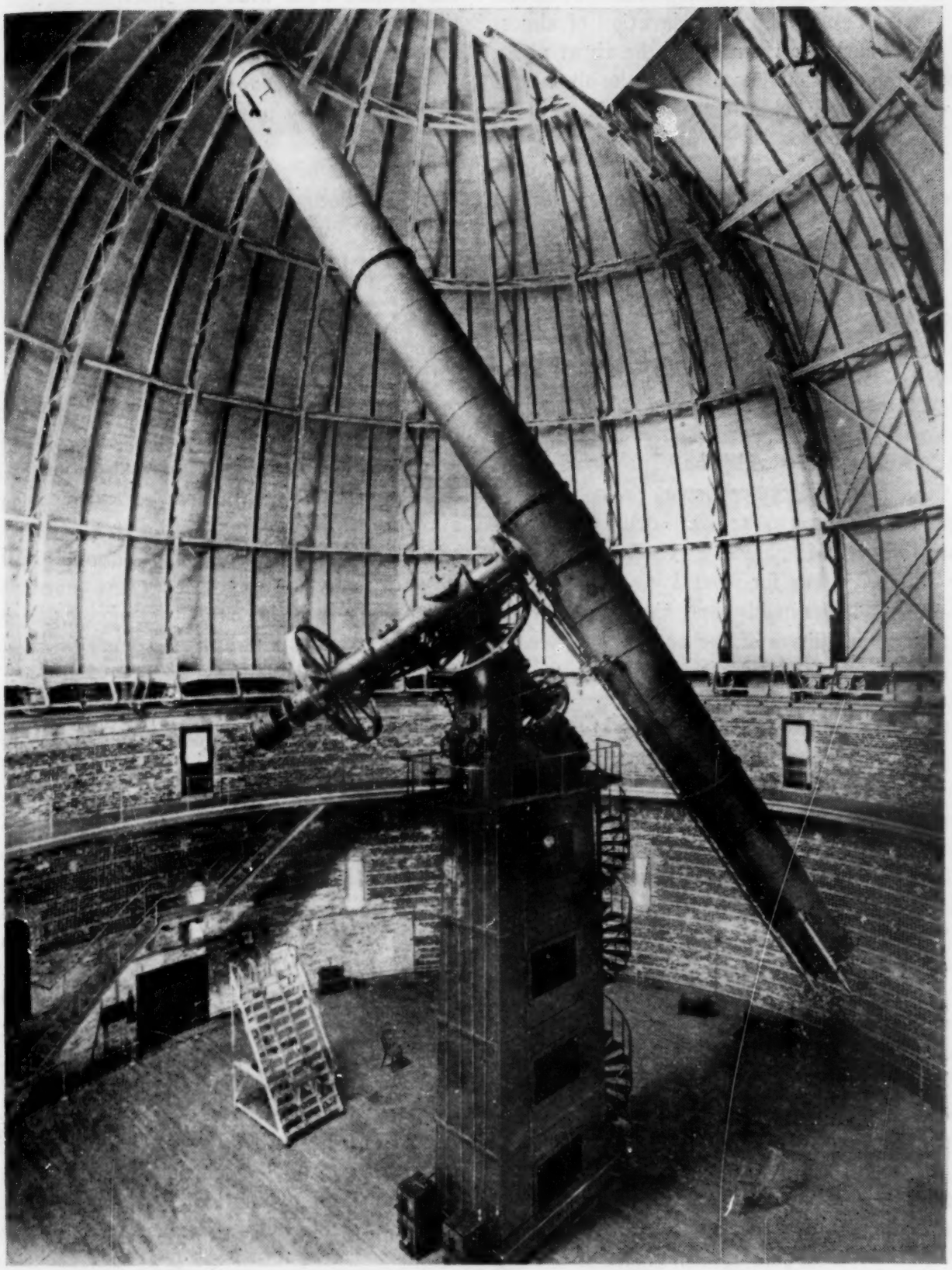
The principal advantage of the 40-inch telescope over all others in existence is in the determination of stellar distances and angular stellar motions. It can also compete with other instruments in the visual and photographic measurement of double stars. But it is surpassed by the large reflectors in most other types of observational work.

Hale intended, from the very beginning, to construct for the Yerkes Observatory a large reflector. His father donated a 60-inch glass disk, and G. W. Ritchey undertook the work of grinding and polishing in the optical shop of the Observatory. The gift of the mirror was conditional upon the University supplying the necessary funds for the mounting and dome. Unfortunately, the University was unable to meet these requirements, and when Hale left the Yerkes Observatory in 1904, he arranged for the transfer of the 60-inch reflector to the Mount Wilson Observatory. With him also went the large horizontal Snow telescope for solar research, as well as several members of the Yerkes staff, including Adams, Pease, Ellerman, and Ritchey.

Before his departure Ritchey completed for the Yerkes Observatory a smaller reflector—one with a 24-inch aperture. This instrument has been used to good advantage for photometric studies of stellar brightnesses by J. A. Parkhurst, for the photography of nebulae, clusters, and other interesting objects by Ritchey, and for the determination of the spherical coordinates of comets and minor planets by Van Biesbroeck.

Soon after Hale's departure for Pasadena, Edwin B. Frost was appointed director. The staff then consisted of S. W. Burnham and E. E. Barnard as senior astronomers, P. Fox as solar physicist, F. Schlesinger as holder of a Carnegie Institution grant for the measurement of stellar distances, J. A. Parkhurst as photometric observer, and S. B. Barrett as secretary and librarian. The principal observing programs during the next 25 years consisted of photography of the sun with Hale's spectroheliograph; determination of stellar distances from photographs with the 40-inch; visual measurements of double stars with the micrometer; determination of positions of comets and other moving objects in the solar system; discovery and measurement of stars of large proper motions across the line of sight; measurement of radial velocities of stars; and determination of the apparent brightnesses of the stars.

Many distinguished astronomers took an active part in this work. S. A. Mitchell, who later became the director of the University of Virginia's McCormick Observatory, and his successor in Virginia, H. L. Alden, were both at



The 40-Inch Telescope of the Yerkes Observatory

one time or another connected with the Yerkes Observatory. F. Slocum, later director of the Van Vleck Observatory, Wesleyan University, and O. J. Lee, later director of the Dearborn Observatory, Northwestern University, were at different times in charge of the solar and parallax observations. After the retirement of Prof. Burnham the work on visual double stars was continued by G. Van Biesbroeck. Prof. Barnard's place was taken by F. E. Ross after the former's death in 1923.

Prof. Frost retired from the directorship in 1932 and was succeeded by the writer of this article. It became more and more evident that the 40-inch telescope was no longer adequate to provide astrophysical material in those branches of the science which employ spectrographs of high dispersion or photometers of very high precision. In 1933 an agreement was completed with the University of Texas providing for the joint operation of a large reflecting telescope, to be constructed from the W. J. McDonald bequest to the University of Texas. The outcome of this cooperative project was the completion, in 1939,

of an 82-inch reflecting telescope on top of Mount Locke, near Fort Davis, Texas. The high elevation of almost 7,000 feet, the remarkable clearness of the air at night, the large percentage of cloudless sky, and the absence of all disturbing terrestrial lights have combined to make this an exceedingly important observing station. Until the completion of the 200-inch telescope on Mount Palomar the McDonald reflector ranked as the second largest telescope in the world.

The idea of cooperation between universities in the utilization of an expensive astronomical telescope has been entirely successful. Both universities have derived fame from the research work of the staff. Separately, neither university could have accomplished even a small fraction of the results which have accumulated during the past 8 years. In order to serve astronomical departments at other universities which have previously been deprived of the use of a large telescope, the cooperative arrangement was extended to include Indiana University and the University of Minnesota. F. K. Edmondson, of the former university, has for several years been using 100 hours of observing annually, and his institution has taken a corresponding share of the operating expenses. Similarly, W. J. Luyten, of Minnesota, makes use of 50 hours per year.

The Yerkes Observatory has had a notable record in the training of astronomers. Among its former students or research assistants were E. Hubble, E. Pettit, A. H. Joy, A. van Maanen, and Horace Babcock at the Mount Wilson Observatory; W. H. Wright at the Lick Observatory; N. T. Bobrovnikoff, P. C. Keenan, and A. J. Deutsch at the Perkins Observatory; J. A. Hynek at the McMillin Observatory, Ohio State University; G. Münch at the Tacubaya Observatory of Mexico; and many others.

The research program of the Observatory during the past 50 years followed closely the path laid out by Prof. Hale in 1897. He wanted to make the Yerkes Observatory primarily an astrophysical institution where astronomy would be coordinated with physics and chemistry. With an important exception—research in the physics of the sun—his hopes and aspirations have been fully realized. After Hale's departure for Mount Wilson the routine work with the spectroheliograph was continued for a number of years, but the results were less important than could have been hoped for. The principal reason for this decline in Hale's own field of study consisted in inability to secure the services of a competent solar physicist.

As a result of scientific developments during the war there has been an enormous increase in the scope of astronomy during the past five years. Fifty years ago the observable part of the spectrum extended from about H and K of ionized calcium to about H_α. The violet limit was set by the transmission of the 40-inch objective and of the dense flint-glass prisms of the stellar spectrograph. The red limit could be reached only with very long exposures by the use of specially sensitized photographic plates. In 1947 the violet limit was extended to about λ 2,000 by the use of spectrographs mounted inside V-2 rockets, and the red limit was extended through the use of micro-wave and radio-wave techniques. Electronics has become an important tool in many astronomical investigations. These and other developments have made it necessary to redirect the work of the Yerkes Observatory and to spend time and energy in the preparation of a new plan of research.

In connection with this need for long-range planning it has been decided to reorganize the structure of the astronomical institutions of the University of Chicago and the University of Texas. The Department of Astronomy will henceforth consist of four units: the two observatories, Yerkes and McDonald, under the directorship of G. P. Kuiper; a section of theoretical astrophysics, which will also be responsible for maintaining the advanced teaching at Yerkes, under S. Chandrasekhar; the *Astrophysical Journal*, with W. W. Morgan as the managing editor; and the teaching section on the campus in Chicago. All four sections will be coordinated by the present writer as chairman of the Department and as honorary director of the two observatories. Under the new arrangement the writer will devote most of his time to research, as well as to the broader policies of the Department; G. P. Kuiper will have charge of the administration of the two observatories; and W. A. Hiltner will continue to serve as assistant director.

NEWS *and Notes*

Henry Norris Russell, retired research professor of astronomy and director, Princeton University Observatory, has been appointed research associate of the Harvard College Observatory.

Linus Pauling, chairman, Chemistry and Chemical Engineering Division, California Institute of Technology, has recently returned from England, where he received honorary D. Sc. degrees from Cambridge University and the University of London, and participated in the International Congress of Pure and Applied Chemistry. Dr. Pauling will return to England in December as Eastman professor at Oxford University. The Eastman professorship is awarded periodically to outstanding American scholars and scientists.

William S. Wilson, head, Department of Physical Sciences, Georgetown College, Georgetown, Kentucky, has been appointed professor of chemistry and head, Department of Chemistry, University of Alaska, College, Alaska.

Barry G. King, formerly assistant professor of physiology, College of Physicians and Surgeons, Columbia University, and during the war, head, Aviation Facility, Naval Medical Research Institute, has been appointed chief, Division of Aeromedical Design and Materiel, Medical Service, Civil Aeronautics Administration.

William H. W. Komp, sanitary engineer director, U. S. Public Health Service, and consultant in malariology to the Division of Health and Sanitation, Institute of Inter-American Affairs, is being transferred from the Panama Canal Zone to the new Division of Tropical Diseases, National Institute of Health, Bethesda, Maryland.

George E. Large, Department of Civil Engineering, Ohio State University, has been appointed chairman of that Department, effective October 1, succeeding **Clyde T. Morris,** who retires this summer after 41 years of service at Ohio State.

George Hugh Berryman, formerly director, Medical Nutrition Laboratory, Office of the Surgeon General, has been appointed chief, Nutrition Branch, Quartermaster Food and Container Institute for the Armed Forces, Chicago.

Frederick S. Nowlan, of the University of British Columbia, Vancouver, has been named visiting professor of mathematics in the Chicago Undergraduate Division of the University of Illinois on Navy Pier.

Harry F. Herbrandson, fellow, Harvard University, has been appointed assistant professor of chemistry, Union College, Schenectady, New York.

Harvey L. Lantz, president of the Iowa State Horticultural Society and on the pomology staff of Iowa State College since 1918, has been appointed head of the pomology subsection of the Iowa Agricultural Experiment Station.

Ira D. Cardiff, Washington Dehydrated Food Company, Yakima, Washington, received the honorary D. Sc. degree from Knox College at its recent commencement.

W. Storrs Cole, professor of geology, Cornell University, has been appointed chairman, Department of Geology.

Charles A. Fowler, Jr., assistant professor of physics, University of California, Berkeley, has been named associate professor of physics on the Seeley W. Mudd Foundation and head, Department of Physics, Pomona College.

Albert F. Blakeslee, Smith College Genetics Experiment Station, who has been a corresponding member of the French Academy of Sciences since 1935, has received notice of a decree of the French Republic signed by Premier Paul Ramadier approving his election as an "Associé étrange" of the Académie des Sciences and the Institut de France. Dr. Blakeslee is the representative of botany among the foreign associates, whose number is limited to 12. He takes the place of the late Simon Flexner, who was director, Rockefeller Institute for Medical Research.

William Hovanitz, Laboratory of Vertebrate Biology, University of Michigan, has returned to Ann Arbor after spending six weeks on a population study of arctic butterflies in Northern Alberta and the Northwest Territories under the sponsorship of the Arctic Institute of North America.

Sidney Kaye, toxicologist, St. Louis Police Department, Missouri, has been appointed toxicologist to the Chief Medical Examiner for the Commonwealth of Virginia, Richmond.

Grote Reber, radio engineer on military radar and communication equipment, Stewart-Warner and Belmont Radio Corporations, has been appointed to the staff, National Bureau of Standards, to investigate cosmic and solar radio noise and to supervise the erection of a German Giant Wurzburg, an extremely large and powerful radar device, to be used to detect solar and cosmic radiation penetrating the earth's atmosphere.

Harold E. Finley, chairman, Department of Biology, Morehouse College, Atlanta, Georgia, has been appointed professor of zoology and head, Department of Zoology, Howard University, Washington, D. C.

H. P. Robertson, Princeton University, will be located at the Norman Bridge Laboratory of Physics, California Institute of Technology, as professor of mathematical physics as of September 15.

Grants and Awards

The Laurentian Hormone Conference has received from the Roche-Organon Company of Nutley, New Jersey, a gift of $15,000 to establish three awards in endocrinology. These will be assigned for 1947 at the Conference at Ste. Adele, Quebec, September 8–13. One award of $5,000 will be made for outstanding recent research in each of the fields of endocrine interest: animal experimentation, hormone chemistry, and clinical endocrinology.

The Committee on Awards consists of Edwin B. Astwood, Thomas F. Gallagher, Roy G. Hoskins, Allan T. Kenyon, Robert L. Noble, and Abraham White.

The Agricultural and Mechanical College of Texas has received a grant of $6,000 from the Research Corporation for the purchase of the Tiselius Adsorption Apparatus and the support of work on lipids by Ralph T. Holman, Department of Biochemistry and Nutrition.

Sidney P. Colowick, Public Health Research Institute of the City of New

York, will receive the $1,000 Eli Lilly and Company Award in Biological Chemistry at the 112th national meeting of the American Chemical Society, to be held in New York City September 15–19, in recognition of his contributions to the knowledge of enzymes. Presentation of the award will be made at a general assembly of the Society Monday evening, September 15. Dr. Colowick's award address on "Hexokinase and Phosphofructokinase" will be delivered at a symposium on "Studies on Enzymes," to be conducted by the Society's Division of Biological Chemistry, September 17.

Colleges and Universities

Harvard University's 11-inch Draper refractor telescope will be shipped to Sun Yatsen University Observatory, Canton, China, on a long-term loan, according to an announcement by Harlow Shapley, director of the Harvard College Observatory. The Chinese residents of Greater Boston have provided the funds for dismantling and shipment to the Chinese observatory, probably the only Chinese institution offering courses in astronomy at this time. Used in the discovery of the first spectroscopic binaries, the Draper telescope is equipped with a correcting lens, has a focal length of 153 inches, and gives photographs having a scale of 53 seconds/millimeter. Built originally for the Lisbon Observatory, Portugal, the telescope was acquired in 1880 by Dr. Henry Draper, who made the first photograph of the Orion nebula while it was in his observatory at Hastings-on-Hudson, New York. In 1886, his widow donated it to Harvard University, where it has been in continuous service ever since.

The University of Cincinnati Observatory has been designated by the International Astronomical Union as the international clearinghouse and publishing center for data pertaining to asteroids. The work will be under the direction of Paul Herget, director of the Observatory and professor of astronomy. Dirk Brouwer, director, Yale University Observatory, and chairman, I.A.U. Commission for Minor Planets, has invited Dr. Herget to take over the editing and publication of the Union's "Minor Planet Circulars." Astronomers in all parts of the world have been invited to send their asteroid observations to Dr. Herget, whose new duties cover work formerly carried on in Berlin.

The Ohio State University is assembling a classification system for more than 11,000 welding patents now in the Davis Welding Library. **W. H. Simon,** University of Toronto, is in charge of the project, which is being financed by the A. F. David Welding Engineering Scholarship and Library Fund. The new classification will enable industries, students, and research workers to obtain more readily information on all patents granted in their specific lines.

The Department of Physics, Rutgers University, has installed a helium liquefier capable of producing temperatures as low as −458°F. The liquefier, a Collins Helium Cryostat, designed by Samuel C. Collins, professor of mechanical engineering, Massachusetts Institute of Technology, and erected at a cost of approximately $20,000, will be used in fundamental studies of the structure of matter, a Rutgers research project sponsored by the U. S. Navy, the Research Corporation of New York, and the Rutgers Research Council. Frank G. Dunnington, head, Department of Physics, is in charge of the project.

Meetings

A three-day clinical conference on diagnosis and treatment of poliomyelitis will be held at Warm Springs, Georgia, September 15–17. The conference, which marks the 20th anniversary of the founding of Georgia Warm Springs, will be led by about 20 authorities in the fields of neurology, pathology, pediatrics, orthopedics, and physical and internal medicine. The papers and discussions will constitute a book on diagnosis and treatment of the disease, to be published next year. Demonstrations of modern methods of treatment will be given by the medical staff of the Warm Springs Foundation. Physicians interested in attending the conference should communicate with the Georgia Warm Springs Foundation, 120 Broadway, New York 5, New York.

The 21st Regional Meeting of the American Geophysical Union will be held as a general meeting of the Union on September 17–20. On September 17 at Wesleyan University, Middletown, Connecticut, there will be a conference on Major Problems in the Tectonophysics of the New England Area, under the chairmanship of Joe Webb Peoples, Department of Geology; at Woods Hole Oceanographic Institution on September 18 Columbus O'D. Iselin, director, will lead a conference on Earth Sciences From the Oceanographic Point of View; and on September 18–20, at the Institute of Geographic Exploration, Harvard University, there will be a conference on Meteorology, Hydrology, and Cosmic Phenomena, under the co-chairmanship of C. F. Brooks, director, Blue Hill Observatory; Harlan T. Stetson, director, Cosmic Terrestrial Research Laboratory, M. I. T.; H. G. Houghton, head, Department of Meteorology, M. I. T.; and H. B. Kinnison, district engineer, U. S. Geological Survey, Boston. Further details may be obtained from conference chairmen or from Richard M. Field, general chairman, South Duxbury, Massachusetts.

The New York Academy of Medicine will hold its 20th Graduate Fortnight October 6–17 at 2 East 103rd Street, New York City. The program, devoted to Disorders of Metabolism and the Endocrine Glands, will be composed of morning panel discussions, afternoon clinics, evening lectures, scientific exhibits, and demonstrations. The lectures will include: October 6, "The Diseases of Adaptation, With Main Emphasis Upon Hypertension," Hans Selye, University of Montreal, and "Adaptation Syndrome in Man," John S. L. Browne, McGill University Clinic, Royal Victoria Hospital, Montreal; October 7, "Energy Metabolism in Obese Persons," Louis H. Newburgh, University of Michigan Medical School, and "Psychological Aspects of Obesity," Hilde Bruch, College of Physicians and Surgeons, Columbia University; October 8, "Relation of the Adrenals to Immunity," Abraham White, Yale University, and "Clinical and Experimental Studies on Adrenal Cortical Hyperfunction," Louis J. Soffer, Mount Sinai Hospital; October 9, "Metabolic Consequences of Immobilization," John E. Deitrick, Cornell University Medical College, and "Use of Androgens in Women," Ephraim Shorr, Cornell University Medical College; October 10, "Studies in Intermediary Metabolism Conducted With the Aid of Isotopic Tracers," DeWitt Stetten, Jr., Harvard University Medical School, and "The Excretion of Urinary Steroids in Health and in Disease," Kon-

d Dobriner, Sloan-Kettering Institute Cancer Research; October 13, "Disrbances in Electrolyte Metabolism in an and Their Management," Daniel Darrow, Yale University School of edicine, and "Role of Amino Acids in utrition," William C. Rose, University Illinois; October 14, "Metabolic Functons in Old Age," Nathan Shock, U. S. ublic Health Service, Baltimore City ospital, and "General Aspects of Cushg's Syndrome," E. C. Reifenstein, Jr., oan-Kettering Institute for Cancer Reearch; October 15, "Hormonal and hemical Factors Regulating Thyroid unction," Rulon W. Rawson, Harvard niversity Medical School, and "Some linical Experiments With Antithyroid ompounds," Edwin B. Astwood, Joseph . Pratt Diagnostic Hospital, Boston; October 16, "Testicular Dysfunction, ome Clinical Aspects," E. Perry McCullagh, Cleveland Clinic, and "Use of ndrogens in Men," Carl G. Heller, Uniersity of Oregon Medical School; Octoer 17, "Why Do Women Abort?", Arhur T. Hertig, Harvard University Medial School, and "Morphological Basis for Menstrual Bleeding," Joseph E. Markee, Duke University. The registration fee is 5.00. Additional information may be ecured from Dr. Mahlon Ashford, 2 East 03rd Street, New York 29, New York.

The Fourth International Congresses on Tropical Medicine and Malaria will be held in Washington, D. C., May 10–18, 1948, under the sponsorship of the Department of State, with the cooperation of 5 other government agencies and 15 scientific societies. Over 60 governments have been invited by the Department of State to send official delegations. As one of the sponsoring societies, the AAAS is represented on the Organizing Committee by Ernest Carroll Faust.

The 12 sections of the scientific program, with their conveners, will be: Research and Teaching Institutes (W. A. Sawyer); Tropical Climatology and Physiology (D. B. Dill); Bacterial and Spirochetal Diseases (T. B. Turner); Virus and Rickettsial Diseases (J. R. Paul); Malaria (M. F. Boyd); Helminthic Diseases (W. W. Cort); Protozoan Diseases (E. C. Faust); Nutritional Diseases of the Tropics (T. T. Mackie). Tropical Dermatology and Mycology (F. D. Weidman); Tropical Veterinary Medicine (R. A. Kelser); Public Health (H. E; Meleney); Medical and Veterinary Entomology (F. C. Bishopp). Officers for the Congresses will be elected at the opening sessions of the plenary and sectional meetings.

There will be scientific and commercial exhibits related to tropical medicine and also motion pictures. Visits will be made to the laboratories of the Department of Agriculture in Beltsville, to the National Institute of Health in Bethesda, and to other institutions in and around Washington.

Two special evening sessions will be held in the Departmental Auditorium in recognition of triumphs of medical science in the tropical field. The first will commemorate the demonstration of the mosquito transmission of yellow fever by Walter Reed and celebrate his admission to the Hall of Fame. The second will commemorate the 50th anniversary of the discovery by Ronald Ross of the method of malaria transmission.

Physicians, scientists, and other professional persons with suitable qualifications and interest in tropical medicine will be enrolled. Those contemplating attendance should write to the Executive Secretary, Fourth International Congresses on Tropical Medicine and Malaria, Department of State, Washington 25, D. C., for the preliminary announcement and the form for advance registration and hotel reservations.

MRC News

The Committee on Growth, acting for the American Cancer Society, is entertaining applications for grants and fellowships. Applications for extension of existing Grants in Cancer Research will be received until October 1; applications for new grants, until November 2. Applications for Fellowships and Senior Fellowships in Cancer Research may be submitted until December 1.

Final decision on applications submitted during this period will be made, in most cases, soon after February 1. Grants approved at this time ordinarily will become effective July 1, 1948. Fellowships may begin at any time determined by the Committee, although these will also usually take effect on July 1.

During the past two years the American Cancer Society, acting upon the recommendation of the Committee on Growth, has awarded 176 grants and 47 fellowships, representing a total expenditure of some $2,700,000. The Committee will continue to recommend support of biological and clinical research dealing broadly with phenomena relating to growth, typical or neoplastic. In the formulation of this program the Committee will be guided, as in the past, by the advice of some 120 scientists, grouped in 20 panels comprising its Sections on Biology, Chemistry, Physics, Chemotherapy, Clinical Investigations, and Fellowships.

Communications regarding grants or fellowships should be addressed to: Executive Secretary, Committee on Growth, National Research Council, 2101 Constitution Avenue, N. W., Washington 25, D. C.

A comprehensive survey of food and nutrition research currently active in the United States is being undertaken by the Food and Nutrition Board with the support of the Quartermaster Food and Container Institute for the Armed Forces. This is a unique effort to compile a detailed record of research in progress in a special field which cuts across so many divergent interests. A register of the type proposed will not only facilitate the coordination of peacetime research in relation to national security and public welfare but will also serve as a basis for quick mobilization of food research resources in event of national emergency. The survey will cover all phases of food and nutrition research, including chemical, physiological, microbiological, technological, psychological, and basic economic studies. Correlation of such studies with regard to health, acceptability, stability, utility, and economy of food will be made.

Subject listings of research in progress pertaining to foods and nutrition are being obtained from directors of research in industry, universities, government, and other agencies. As a supplementary source of information, food and nutrition projects receiving financial support from foundations, public trusts, industry, and other funds are being recorded. The information received will be so classified and coded that any phase of research in progress can be readily extracted and correlated with other phases.

A roster of personnel engaged in food and nutrition research is also being developed in collaboration with the Office of Scientific Personnel.

C. G. King, scientific director, Nutrition Foundation, is chairman of the Committee on Survey of Food and Nutrition Research which will supervise the project

and collaborate in the preparation of periodic reviews and reports. Mildred Ragan, technical secretary for the Committee, and LeRoy Voris, executive secretary, Food and Nutrition Board, are handling the operational details for the National Research Council.

Recent Deaths

William W. Watts, 87, emeritus professor of geology, Imperial College of Science and Technology, died in London on July 30.

George H. Hallett, 76, professor emeritus of mathematics at the University of Pennsylvania, died August 13 in West Chester, Pennsylvania.

Terence Thomas Quirke, 61, professor of geology, University of Illinois, died August 19 of a heart attack. Dr. Quirke is the author of a comment appearing in this issue.

Boyd Coe Dennison, 66, professor of electrical engineering at the Carnegie Institute of Technology, died August 19 in Pittsburgh, Pennsylvania.

Comet Wirtanen, a new comet named for its discoverer, C. A. Wirtanen, was seen for the first time in California on July 18. Two observations have since been reported to the Harvard College Observatory from Lick Observatory, Mount Hamilton, California, according to announcement by Science Service. The comet, which can be seen only with a powerful telescope, is traveling slowly north and west near the celestial equator between the constellations Aquarius and Aquila and is of the 12th magnitude.

The National Government of China has announced a revised set of organic laws for the Academia Sinica, the National Academy of China. The revision has to do mainly with election of academicians from among Chinese scholars of distinction. The Academy, founded in 1926 as the highest academy of learning in China, is directly under the National Government, from which it receives financial support. Its first president was Tsai Yuen-Pei, who served until his death in 1940, after which Chu Chi-Hua, educator, was appointed acting president.

Aside from coordinating and promoting research in all branches of organized knowledge, the Academy's laws provide for the establishment of some 23 research institutes. At present only 13 are organized, each with its own director, research staff, technicians, and clerks: Mathematics, Astronomy, Physics, Chemistry, Geology, Zoology, Botany, Meteorology, History and Philology (divided into sections on History, Philology, Archaeology, and Ethnology), Social Sciences, Medicine, Engineering, and Psychology. The institutes are administered by a secretariat headed by a secretary general and a number of staff members appointed by the president. A. Pen-tung Sah is the present secretary general with a main office at Chi Ming Ssu, Nanking, and a branch at Shanghai (320 Yoyang Road).

The new provision for election of Academy members is in line with that of academies in other nations. Following election of an initial group of 80–100 members from nominees of various organizations and institutions in China, a maximum of 15 may be elected each year. There will also be a representative Council, members of which will serve for three years.

In addition to monographs published by the various institutes, the Academia Sinica publishes two journals: *Science Record*, containing brief original scientific articles in English, French, or German, which has been issued twice since 1941 under the chief editorship of Y. H. Woo, physicist; and *Shyue Shuh Hueh Kan*, published in Chinese, also issued only twice since 1941, which contains review articles, biographies of scholars, and abstracts of research work.

The U. S. Atomic Energy Commission has appointed an advisory Scientific Personnel Committee to study employment conditions and problems of scientific and technical personnel in the research institutions which are working on the Atomic Energy Commission program. Its report will include detailed recommendations and supporting data based on practices in government, industry, and educational institutions, taking into account the unique mission of the Atomic Energy Commission. This report, which the Committee will submit to the Commission, will recommend personnel policies for the Commission research program to enable the Commission to obtain the services of qualified research personnel without adverse effect upon academic and industrial employers. The Committee, which will be a continuing group, includes the following members: F. Wheeler Loomis, professor of physics, University of Illinois, chairman; Morris P. Carpenter, executive director, Whiting Laboratories, Standard Oil Company of Indiana, Whiting, Indiana; Farrington Daniels, chairman, Board of Governors, Argonne National Laboratory, and professor of chemistry, University of Wisconsin; W. A. Hamor, associate director, Mellon Institute; William B. Harrell, business manager, University of Chicago; and Lawton D. Geiger, Iowa Area Manager, U. S. Atomic Energy Commission, Ames, Iowa, executive secretary.

The National Registry of Rare Chemicals, 35 West 33rd Street, Chicago 16, Illinois, lists the following wanted chemicals: dodecamethylene chloride; 2,7-diaminofluorene; brazilin; desoxyguanosine; trimellitic acid; phloretin; perthiocyanicacid; carbonyl sulfide; deuteroammonia; diborane; lithium deuteride; furazan; 1,3,4-oxadiazole; 3-phenylcyclopentene; benzochrysene; benzoperylene; benzofluorene; jojoba oil; ferrous glycinate; and vinyl dimethylamine.

The 10th Annual Louis Gross Memorial Lecture will be delivered at the Jewish General Hospital, Montreal, under the auspices of the Montreal Clinical Society, October 29, at 8:30 P.M., by I. Arthur Mirsky, director, May Institute for Medical Research, and associate professor of experimental medicine in psychiatry, University of Cincinnati. Dr. Mirsky's topic will be: "Biology of Metabolic Disease in Man."

The Department of Biology, U. S. National Museum, was reorganized on July 31 to form two separate Departments, Zoology and Botany. The Department of Zoology for the present will include the Divisions of Mammals, Birds, Reptiles and Amphibians, Fishes, Insects, Mollusks, Marine Invertebrates, and Echinoderms, **Waldo L. Schmitt,** head curator of Biology, becoming head of Zoology. The Divisional staffs remain unchanged. The newly-established Department of Botany, with **E. P. Killip** as head curator, comprises the Divisions of Phanerogams, Grasses, and Cryptogams. **Jason R. Swallen** is curator of the Division of Grasses. Mr. Killip will for the

present act also as curator of the other divisions. Associate curators **E. C. Leonard, C. V. Morton,** and **E. H. Walker** are assigned to the Division of Phanerogams, and **Paul Conger,** in charge of the Section of Diatoms, is assigned with his collections to the Division of Cryptogams. It is expected that this reorganization will enable the staff working with the collections designated as the U. S. National Herbarium to give them better care and to respond more promptly to the many requests for information received from all parts of the world.

The National Bureau of Standards, in cooperation with the Office of Naval Research, has just published in loose-leaf form the first tables in a new and comprehensive compilation of "Tables of Selected Values of Chemical Thermodynamic Properties," which bring together for the first time all available published data of chemical thermodynamic properties. One set of these tables, which are published in three parts, is being furnished to each university Department of Physics, Chemistry, or Engineering. U. S. Government laboratories, research institutions, and industrial laboratories may obtain one set each on request to the Bureau.

Make Plans for—

American Roentgen Ray Society, September 14–19, Atlantic City, New Jersey.

American Chemical Society, September 15–19, New York City.

Illuminating Engineering Society, September 15–19, New Orleans, Louisiana.

American Institute of Electrical Engineers, Middle Eastern District Meeting, September 23–25, Dayton, Ohio.

American Public Health Association, October 6–10, Atlantic City, New Jersey.

American Academy of Ophthalmology and Otolaryngology, October 12–17, Chicago.

American Association for the Advancement of Science, 114th Meeting, December 26–31, Chicago, Illinois.

COMMENTS
by Readers

In solar radiation work the unit called the gram calorie per square centimeter per minute is very frequently used; for longer time intervals, such as an hour or day, for example, the gm cal/cm²/hr or gm cal/cm²/day is used, when appropriate. These units are somewhat cumbersome to write and even more awkward to say.

A more convenient unit is therefore needed. According to F. Linke (*Handb. Geophys.*, 1942, **8,** 30) the "langley" has been proposed to designate the gm cal/cm²/min, in honor of Samuel P. Langley, who, as the first director of the Astrophysical Observatory of the Smithsonian Institution, contributed greatly to the study of solar radiation and its depletion by various gases in the earth's atmosphere.

However, in view of the need of considering longer time intervals than a minute, it is herewith proposed that the "langley" be defined as the gm cal/cm², where "gm cal" denotes the 15°C gm cal. It is also proposed that the written abbreviation of "langley" be "ly"; to shorten the word in other ways might tend to confuse it with other units.

Having adopted the new unit we may now speak of the langley per minute, the langley per hour (and so forth), which will be written as ly/min and ly/hour. (L. B. ALDRICH, *Smithsonian Institution, Washington, D. C.*; H. WEXLER and S. FRITZ, *U. S. Weather Bureau, Washington, D.C.*; I. F. HAND, *U. S. Weather Bureau, Boston*; A. COURT, *Office of the Quartermaster General*, and MAJOR W. P. MELLEN, *Air Corps, Washington, D. C.*)

A remarkable set of rainbows was seen from 8:00 until about 8:15 P.M. (C.D.T.) on July 20, 1947, at Urbana, Illinois. The main primary rainbow showed a continuous band of clear color. The most unusual part of this bow was the brilliance of the violet band, which at times exceeded in intensity that of the blue and green bands. From top to bottom the colors in a primary rainbow run: red, orange yellow, green, blue, indigo, violet. Usually the indigo and violet bands are quite faint, whereas in this case they were unusually bright.

A secondary rainbow was very plain, above and outside the arc of the primary bow. In this, as is usual, the order of colors was reversed, with red at the bottom and green above. It is uncommon for the blue, indigo, and violet bands to show above the green in the secondary rainbow, and this was no exception. However, the width of the secondary bow, even without the blues, was about equal to that of the whole primary bow. Between the primary and secondary bows the sky appeared to be lacking in light. It was dark, leaden gray in color.

Beneath and within the curve of the primary rainbow were the so-called supernumerary rainbows, very brilliantly exhibited. Although these are referred to as "familiar" phenomena by W. J. Humphreys in his *Physics of the air* (1920, pp. 456–482), they have never before been seen by the writer or by many other mature persons. In this case the position of the sun, due to the time of day, was almost ideal for rainbow phenomena. The whole band of rainbows appeared to lie within a vertical angle of about 20°, from about 60–40° above the horizon, with the zenith of the bows in a direction about 10° S.E. from the observer. Two supernumerary bands of color beneath the unusually brilliant violet of the primary bow were visible to this observer, and Lt. Col. J. S. Shaplund, C.E., U. S. Army, told the writer that he was able to distinguish still another inner band from his place of observation. The only colors distinguishable in these supernumerary bows were green and red-violet. The bands of green and violet were very narrow, their width being about that of green and blue only

in the primary rainbow. Beneath the primary bow, ending with brilliant violet, were green, violet, green, violet, and green, violet. The first repetition of green and violet was clear over the larger part of the primary bow, but the second and third showed only from time to time and then most clearly near the zenith of the arcs.

Supernumerary rainbows are said usually to show only green and red. They are interference phenomena, and in the case here reported it seems as if the red was superposed over the violet so as to produce the unusually brilliant bands of red-violet even in the primary bow. A complete explanation of these phenomena is presented by Humphreys, as noted above. (TERENCE T. QUIRKE, *Department of Geology and Geography, University of Illinois.*)

Everyone who has had occasion to teach vitaminology must have experienced considerable difficulty with the commonly accepted terminology, both because of the cumbersomeness and because of the incorrect implications of some of the terms used. In the interest of further simplification and clarification, the following suggestions are offered:

(1) Since vitamin A activity results from activation of carotene, it is suggested that "accarene" be adopted as an official name. This term is a condensation which implies nothing as to its physiological action or therapeutic effects; it is a short term, and yet the chemical relations are not too completely obscured. The rather commonly used "axerophthol" is objectionable not only because of its length and rather awkward pronunciation, but more importantly, because it implies one rather superficial and nonspecific therapeutic influence. This is always objectionable, because it implies that the vitamin is of importance only when deficiency occurs.

(2) It is suggested that "ossiferol" be substituted for "calciferol" as a specific designation for vitamin D_2. The objection to the older name is that it leaves out of consideration all reference to the influence of the vitamin on the metabolism of phosphorus in relation to bone. Certainly, this phase of its action is as important, if not more so, than the influence on calcium. "Calciferol" does have the merit of referring to a physiological process but to only a limited part of it.

(3) It is suggested that, since vitamin D_3 is produced by activation of 7-dehydrocholesterol, this latter term be telescoped to "sedesterol." As in the case of vitamin A, there is no implication of chemical nature or of physiological action; the word is euphonious and not cumbersome.

It seems desirable that all names of vitamins be based on (a) chemical composition, (b) physiological rather than therapeutic action, or (c) be distinctive but nonspecific. "Ascorbic" acid is especially objectionable because it refers to a deficiency state rather than to chemical composition or physiological function in healthy organisms. From this point of view, it would be highly preferable to restore the original chemical designation of hexuronic acid.

The above criticisms apply equally well to tocopherol as a designation for vitamin E activity. However, no suggestion is made for any change until its function in the human is better understood. (C. I. REED, *University of Illinois, Chicago Professional Colleges.*)

Book Reviews

Fundamental theory. A. S. Eddington. Cambridge, Engl.: at the Univ. Press, 1946. Pp. viii + 292. 25/-.

This posthumous work of the great British astronomer, which supersedes his *Relativity theory of proton and electron* (Cambridge, 1936) and *The combination of relativity theory and quantum theory* (Dublin, 1943), was prepared for the press by E. T. Whittaker, of Edinburgh University. It represents the clearest expression which Sir Arthur achieved of his theory of the relation of relativity theory and quantum theory and his deduction of the value of certain fundamental constants of nature, such as the masses of the electron and proton, the fine structure constant, the rate of recession of the nebulae, the number of particles in an Einstein universe, and the nuclear-range constant. On pages 66 and 105, and in Chapters IX and XI are set forth the *calculated* values of more than 30 constants of nature, nearly all of which are in most remarkable agreement with experiment. The reviewer knows of no other theory which achieves such accuracy of prediction over so wide a range of physical phenomena.

Since Eddington worked almost completely alone for the last 20 years of his life, the hidden assumptions in his physical reasoning are not always the same as those of more well-known schools of quantum theorists. This accounts for the fact that those who approach his theory after a thorough grounding in more conventional methods find it very difficult to understand and even repellent. Further, since he created his theory by daring intuitions rather than by careful argumentation (as happens with any essentially new theory) and since it seems to require for its adequate formulation much abstract algebra with which Eddington was not too well acquainted, there are occasional gaps and even inconsistencies in the logic of his presentation. However, even though Eddington's arguments are not always convincing, his formulas are related to one another in such an astonishing way, which cannot be explained by chance, and result in the prediction of so many facts in complete agreement with experiment that the reviewer is persuaded that the theory is essentially correct while he admits that the rationale of the dependence of the formulas on Eddington's basic notions is still far from satisfying.

Eddington's reputation as an *astronomer* is already secure. If the above judgment as to the value of *Fundamental theory* proves to be well founded, he will rank with Newton and Einstein as one of those few geniuses who have effected fundamental revolutions in our knowledge of the physical world.

A. J. COLEMAN

13 rue Calvin, Geneva, Switzerland

Time, knowledge, and the nebulae: an introduction to the meanings of time in physics, astronomy, and philosophy, and the relativities of Einstein and of Milne. Martin Johnson. New York: Dover, 1947. Pp. 189. $2.75.

Milne's Kinematical Relativity, which is derived from definitions of distance and time in terms of simultaneity and succession at the observer, was first published some 15 years ago. It is considered by many (including Dr. Johnson) to be as great a philosophical advance as Einstein's Relativity of 1904 or Newton's Laws of Motion.

In this little book Dr. Johnson presents in readable form a survey of various relativities and cosmologies together with their philosophical implications. Two basic themes are developed. The first concerns the nature of time, this leading to a rejection of causality in favor of "functional dependences," and to a critical examination of the various contexts in which "time" is used. The second and more important theme has to do with the *Principle of Communicability*, proposed by Johnson as the philosophical basis of all science. On this principle, the relativity transformations and time scales of Milne are shown to be necessary in order that experience (*i.e.* the Laws of Physics) may be communicated intelligibly from one observer to another.

Many scientists will want to bring themselves up to date on relativity and the changing philosophy of science by reading this excellent work. Nonmathematical readers will find most of the mathematics easy to follow, although the addition of simple space-time diagrams would have been an immense help to the uninitiated reader. It is unfortunate, too, that there is scarcely mention of geological time, of time in evolution, or of accelerated reference systems. The spiral form and the red-shifts of the spiral nebulae are discussed fully, but the significance of Hubble's surveys determining density distribution is ignored.

Time, knowledge, and the nebulae should stimulate further research among astronomers and physicists by pointing to new possibilities in the interpretation of data. As Prof. Milne says in the forward: "... only ... through the consideration of the problem of time, can the important questions of physics be properly investigated."

THORNTON PAGE

Yerkes Observatory, Williams Bay, Wisconsin

Methods of mathematical physics. Harold and Bertha Swirles Jeffreys. Cambridge, Engl.: at the Univ. Press, 1946. Pp. vii + 679. $15.00.

The authors preface their large Cambridge volume with the statement: "This book is intended to provide an account of those parts of pure mathematics that are most frequently needed in physics." This they have done by giving an account of fairly extensive topics, principally in analysis beyond the calculus, and by then applying methods developed therefrom to selected problems in physics. The consequence is a most useful compendium of special methods and results, rich in problems but somewhat lacking in general points of view which would tie the material treated into a more unified whole.

In developing the more purely mathematical topics the authors have been guided by the sound principle that high standards of rigor are as necessary for applicable as for pure mathematics; it is recognized that in order to achieve such rigor without undue complications some sacrifice of generality must be made. Thus, in proving theorems in real and complex variable, conditions are postulated which are sufficiently broad to cover the proposed applications, and the theorems are then proved with the rigor appropriate to the subject; the authors are justifiably less concerned with whether the conditions postulated are necessary for the truth of the theorem. In this spirit an admirable exposition is made of series, integration, calculus of variations, conformal mapping, linear differential equations, and a host of other topics. The chapters on vectors, tensors, matrices, and operators present and apply a wealth of useful results, but it seems to the present reviewer that their treatment from a more fundamental algebraic point of view would lead to a deeper understanding, both of the topics in themselves and of their role in modern physics.

The physical fields to which the mathematics is applied are almost as broad as physics itself—including, as they do, dynamics, hydrodynamics, elasticity, and electromagnetism, among others. It is to be observed that these applications are to specific topics in these fields and that a fuller appreciation of their significance requires some previous familiarity with the fields. Perhaps the greatest lacuna is the quantum theory, which is touched upon altogether too lightly in view of its importance in modern physics and astrophysics, and which offers an excellent opportunity to draw together several fields under a unified mathematical viewpoint.

Altogether the book offers a wealth of well-treated material which should prove most useful as a source or reference for students, teachers, and advanced workers in physical science. It is a source of gratification to note that physically and typographically the Cambridge University Press has here done a job which is well up to their high prewar standards.

H. P. ROBERTSON

California Institute of Technology

The Soochow astronomical chart. W. Carl Rufus and Hsing-Chih Tien. Ann Arbor: Univ. Michigan Press, 1945. Pp. 24. (Illustrated.)

In the Wên Miao temple near Soochow, Kiangsu, China, there is a star map, about three feet in diameter, accompanied by a text prepared in 1193, engraved in stone in 1247. Eduard Chavannes published, in 1913, a reproduction of the chart, with a French translation of the text, but without an identification of the asterisms and stars or a translation of their names ("L'Instruction d'un futur empereur de Chine en l'an 1193, Carte astronomique," *Acad. Inscr. Belles-Lettres, Mém. Asie orientale*, 1913, **1**, 43–57). The present publication offers, in addition to a good reproduction of the star map and of the accompanying text, an introduction, a description of the star map, an annotated translation of the text, and tables of 313 asterisms and 1,440 stars, with their names and, when feasible, their identification.

The text of the "instructions for a future emperor" is a blend of cosmography and political astrology. The star map has the North Pole in the center; the three concentric circles mark the circumpolar asterisms (ca. 35°, latitude of Kai-Feng Fu, Honan, seat of the Government, 1214–67), the equator, and the limit of southern asterisms (ca. −55°). The 28 lunar mansions —of unequal extent—are shown by radial lines extending from

the circumpolar circle to the rim of the map. The ecliptic has an obliquity of about 24°. The Milky Way (The River of Heaven) is outlined. The purpose of the map is primarily astrological; the identification of many stars shown on it is a hopeless task.

This publication is a companion work to "A Korean star map," by W. Carl Rufus and Celia Chao (*Isis*, 1944, **35**, 316–326).

ALEXANDER POGO

Carnegie Institution of Washington

The earth and the stars. C. G. Abbot. New York: D. Van Nostrand, 1946. Pp. xii + 288. (Illustrated.) $3.75.

This book by Dr. Abbot is like a tour in the universe of space and time with a guide who is enthusiastic and optimistic and has an interest in people as well as in stars. The author impresses the reader not only with the vastness of the universe, but with its beauty, its unsolved problems, and the significance of intelligent life.

The material of the 1926 edition has been rearranged, some has been omitted, and much new has been added. The print is larger and the paper better. A few inadvertent slips have been noted which could be corrected by a sheet of errata inserted by the publisher in each copy of the book. Plates referred to in the text as XIII, XX, and XXII are missing; plates of different subjects bear those numbers.

The author begins with descriptions of appearances. Then he explains interpretations given them, from ancient myths to results obtained with modern equipment. Two chapters on the sun include a discussion of the sun's periodicities, their influence on weather, and the possibility of utilizing the power in solar radiation. So modest is the treatment of Dr. Abbot's own part in these researches that the reader would not realize how large it is. Topics related to astronomy, such as atoms, calendars, star places, and navigation, are explained. In the last chapter, "Some Famous Astronomers and Famous Instruments," are described feelingly the high lights of astronomical history from Hipparchus to the construction of the 200-inch telescope. Appendixes contain astronomical tables, a brief explanation of tides, a glossary, and an index.

LEAH B. ALLEN

Hood College, Frederick, Maryland

Making your own telescope. Allyn J. Thompson. Cambridge, Mass.: Sky, 1947. Pp. xi + 211. (Illustrated.) $3.50.

This volume contains a reasonably consecutive set of directions for the construction of a reflecting telescope of 6-inch aperture and 48-inch focal length. After a brief account of the discovery and development of the telescope, the author gives a list of the materials and equipment needed to make the telescope mentioned above, and proceeds to tell how to grind the mirror, prepare a pitch lap, and polish and figure the mirror. He describes the making of a diagonal mirror, but limits himself to the description of three common types of eyepieces, Huyghenian, Ramsden, and Kellner, referring the reader to other books for complete details on their construction.

Plans are given for two equatorial mountings made from standard pipe fittings. In the chapter "Aluminizing and Cleaning," the author assumes that the telescope maker will send his mirror away to be aluminized and says only that "instructions for silvering by the Brashear and other processes may be found in optics, telescope making and physics laboratory texts."

Mr. Thompson has served as an instructor in telescope-making classes at the Hayden Planetarium in New York City; his book indicates that he has met most of the problems encountered by amateurs. Many of the solutions proposed are the standard ones, tried and proven by several decades of American amateur telescope makers. Considering how often the mirror and tool stick together for an unskilled amateur, the author's suggestion, "If this occurs, use a carpenter's wooden clamps to separate them, or wedge the tool on a bench, hold a block of wood against the side of the mirror, and free it with a sharp blow of the hammer," seems like powerful medicine. A little more emphasis on prevention and one or two less drastic cures would make worthwhile additions to the book.

The author appears to be optimistic about polishing (2–6 hours, p. 67) and needlessly pessimistic about figuring (15–25 hours, p. 196). When the testing of three nearly-plane surfaces against each other is discussed (p. 102), no mention is made of 'saddle-shaped' surfaces, which are common in small sections of plate glass; no clue is given as to what may be done with them. Other small omissions are noted, but a second edition will doubtless take care of them in due time.

As it is, the book is an excellent one for the man who is making his first reflecting telescope.

CHARLES H. SMILEY

Ladd Observatory, Providence, Rhode Island

Scientific Book Register

FEDERER, CHARLES, and FEDERER, HELEN. *Splendors of the sky.* (2nd ed. rev.) Cambridge, Mass.: Sky, 1947. Pp. 36. (Illustrated.) $.35.

GAMOW, GEORGE. *Atomic energy in cosmic and human life: fifty years of radioactivity.* Cambridge, Engl.: at the Univ. Press; New York: Macmillan, 1947. Pp. x + 161. (Illustrated.) $3.00.

JONES, HAROLD SPENCER. *John Couch Adams and the discovery of Neptune.* Cambridge, Engl.: at the Univ. Press; New York: Macmillan, 1947. Pp. 43. $.75.

LEY, WILLY. *Rockets and space travel: the future of flight beyond the stratosphere.* New York: Viking, 1947. Pp. viii + 374. (Illustrated.) $3.75.

SPURR, J. E. *Features of the moon.* Pt. I: *Geology applied to selenology; the Imbrian Plain region of the moon.* Pt. II: *The features of the moon.* Lancaster, Pa.: Science Press, 1945. Pp. x + 112 (Pt. I); xiii + 318 (Pt. II). (Illustrated.) $5.00.

STERNS, MABEL. (Compiler.) *Directory of astronomical observatories in the United States.* Ann Arbor, Mich.: J. W. Edwards, 1947. Pp. x + 162. (Illustrated.) $2.85.

————. *Harvard College Observatory, the first century: a review of the past and a preview of the future.* Cambridge, Mass.: Harvard College Observatory, 1946. Pp. 94. (Illustrated.) $1.00.